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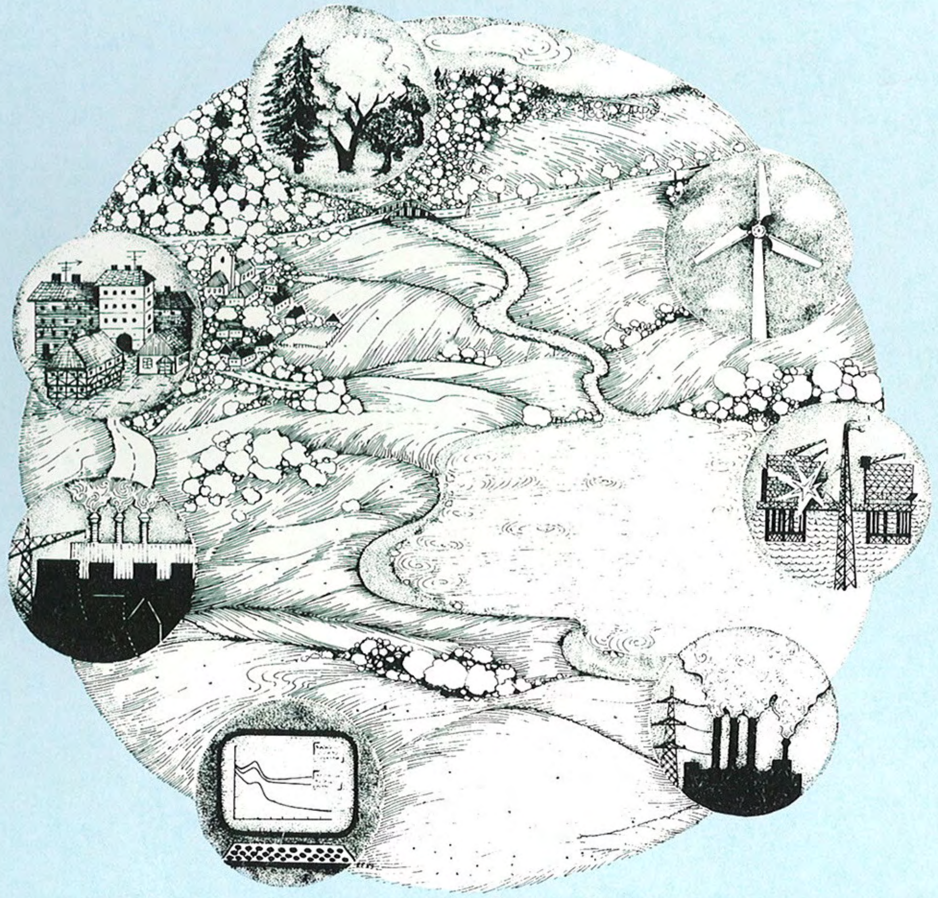
Systems Analysis Department Annual Progress Report 1990

Edited by Hans Larsen and Gordon A. Mackenzie



Risø National Laboratory, Roskilde, Denmark
March 1991

Abstract The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1990. The Department is made up of the Cognitive Systems Group, the Risk Analysis Group, the Energy Systems Group and the UNEP Collaborating Centre for Energy and Environment. The report includes lists of publications, lectures and staff members.

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Contents

1. Introduction

The Systems Analysis Department is engaged in R&D concerning methods and models dealing with the interplay among various technologies, systems and humans. The methods and models developed are applied mainly within the energy and industrial sectors.

In 1990 major organizational changes had taken place at Risø. In March the Environmental Model Group was disbanded, the work on soil chemistry modelling was discontinued, and the staff formerly engaged in this work was transferred to the Energy Systems Group. At the same time, the Cognitive Systems Group was established as a new group in the department. This group is working in research areas related to human cognition in connection with the introduction of advanced information technologies. The activity was transferred from the former Information Technology Department. On 1 October 1990 the UNEP Collaborating Centre on Energy and Environment was established as a new unit in the Department. The purpose of the Centre is to promote the incorporation of environmental considerations into energy planning and policy worldwide, particularly in the developing countries.

Hence, the Department now comprises the Energy Systems Group (ESG), the Risk Analysis Group (RAG), the Cognitive Systems Group (COG), and the UNEP Collaborating Centre (UCC).

The R&D activities of the Department now include cognitive modelling, cognitive systems design, reliability, risk management, consequence modelling, energy-environmental modelling, and assessment of energy and environmental technologies.

The Department is multidisciplinary and the permanent staff numbers 35 economists, social and behavioural scientists, natural scientists, and engineers, together with 5 research students and 7 supporting staff.

The activities of the Department in 1990 were financed 50% by government appropriations and an equal amount by funds derived from research contracts. The work involves close collaboration with Danish and foreign universities, research institutes, corporations, and consulting firms, as well as national ministries and international organizations such as the Commission of the European Communities, the Nordic Council of Ministers, UN, UNEP, IEA, IIASA, and WB.

The Risk Analysis Group conducts research and development concerning reliability, consequence modelling, and risk management. These research areas are based on the demand for high reliability of modern large complex industrial plants for safety and economic reasons.

In 1990 the group participated in a joint European research project together with JRC-Ispra, VTT in Finland, and others, to develop an integrated set of advanced software tools for making safety and reliability analyses using a knowledge-based approach (STARS). Risø is primarily developing knowledge bases for plant, units, and chemical substances.

In collaboration with a number of other European research institutes, RAG participates in the project Physical Modelling of Torch Fires carried out under the CEC research programme Major Technological Hazards. In 1990 the work covered the experimental part of the project in the form of full-scale field experiments. In 1990 work on a new project ENTOREL was initiated as part of the CEC Teleman project. Further, work has been continued on the development of an online decisional support system for reliability-centred maintenance using a fault-tree system representation.

A new Ph.D. study has been initiated dealing with the identification of toxic substances that are generated during fires involving chemicals. As was the case in previous years, in 1990 the group had also carried out a number of specific risk analyses for chemical industries and offshore installations.

The Cognitive Systems Group is engaged in interdisciplinary research on cognitive system design, cognitive modelling and risk management. The introduction of advanced information technology has changed the working conditions for many people during recent years. As elementary human work routines become mechanized and automated, the action possibilities of the individual become greater.

In 1990 the research concerning cognitive system design and modelling had been centred around the participation in the project Modelling of Human Actions in Work Context (MOHAWC). This work was carried out as part of the CEC ESPRIT II basic research programme in which a number of European universities participated with Risø as main contractor.

In 1990 the group was also involved in research on risk management. In this context it participated in a project IT Support for Emergency Management (ISEM), carried out as part of the CEC ESPRIT programme in collaboration with VTT in Finland and a number of European companies, again with Risø as main contractor.

The Energy Systems Group undertakes research and development concerning models for energy and environment and utilizes these in connection with energy and environmental planning. Furthermore, the group conducts assessments of energy and environmental technologies.

In 1990 the group contributed to the preparation of the new Danish plan "Energy 2000". The group's involvement included the development of the Bruntland Scenario Model, numerous studies and assessments, and responsibility for writing a number of annexes to the plan.

In 1990 the group has continued to participate in the energy and environmental modelling programme of the Commission of the European Communities, especially concerning the models EFOM and HERMES. The group has become responsible for national emission inventories as a participant in the Danish Centre for Atmospheric Research, and for Danish participation in the CEC CORINAIR project aimed at establishing a common European emissions inventory.

A number of projects had been initiated within the framework of the Nordic Council of Ministers; these have included integrated energy and environmental planning, energy savings in the electricity sector, and environmental planning in the Baltic region.

In 1990 a new Ph.D. project on integrated models and uncertainty was started.

The group has been involved in energy planning activities in developing countries. In 1990 this has involved assessment studies on wind energy in Egypt and energy planning at the Cape Verde Islands.

On 1 October 1990 the UNEP Collaborating Centre on Energy and Environment was established as a new unit in the Department. The aim of the Centre is to promote the incorporation of environmental considerations into energy planning and policy worldwide, particularly in developing countries.

The Centre is financed jointly by the United Nations Environmental Programme (UNEP), the Danish International Development Agency (Danida), and Risø, provisionally for a four-year period. The Centre will be staffed by five professionals when fully operational in 1991.

2. Risk Analysis Group

The activities within the Risk Analysis Group comprise research and development in the areas of reliability, consequence modelling, and risk management.

Large complex industrial plants demand high reliability due to requirements of high productivity and safety. Consequently, there is a need for developing methods and tools to support reliability and risk analyses of industrial plants with the aim of identifying weaknesses in design or operation. Also, methods must be developed to assess the consequences of accidents at industrial plants affecting the staff, equipment, environment, and society at large. Finally, methods are worked out aimed at controlling and managing the risks inherent in industrial activities.

The activities include the development of methods mainly during participation in international research projects, and transferring knowledge to industry and authorities either by carrying out specific risk or reliability analyses or by lecturing and training.

The main activities carried out in 1990 are described in the three following sections.

2.1. Reliability

The activities are carried out to identify the causes of failures and hazards that affect reliability and/or safety at industrial plants and predict the failure rate.

In 1990 work was concentrated on three areas:

- developing an integrated set of advanced software tools for safety and reliability analyses (STARS) using a knowledge-based approach.
- developing a guide using a modification of the HAZOP method to aid in assessing occupational hazards in the iron and chemical industries.
- applying reliability methods in maintenance planning based on failure reports, condition monitoring and control system measurements.

Further, the methods available have been applied in a comprehensive study of the reliability of the technical installations used and planned for use in the Great Belt Link. This work is expected to be completed in 1991.

In 1990 work on a new four-year research project ENTOREL was initiated as part of the CEC TELEMAN programme. The aim is to develop a tele-operated manipulator which is able to work in a disordered environment. The design work will be carried out with reliability analysis as an integrated element.

2.1.1. STARS, Software Tool for Advanced Reliability and Safety Analysis.

The STARS program package features a knowledge-based approach to systems safety and reliability analysis. STARS represents a new generation of programs following RIKKE (developed at Risø) and CAFTS (developed at JRC-Ispra) both of which are programs for automatic fault tree construction.

The main purpose of the STARS package is to assist the process designer during the design of complex process installations.

The STARS programme is developed as a collaborative project among four institutions: Risø National Laboratory, JRC-Ispra, Technical Research Centre of Finland, and the Italian company Tecsa. Several research institutes and industrial companies are also participating as affiliates.

The effort at Risø in 1990 was concentrated on the development of a set of knowledge bases for use in the qualitative risk analysis part of STARS.

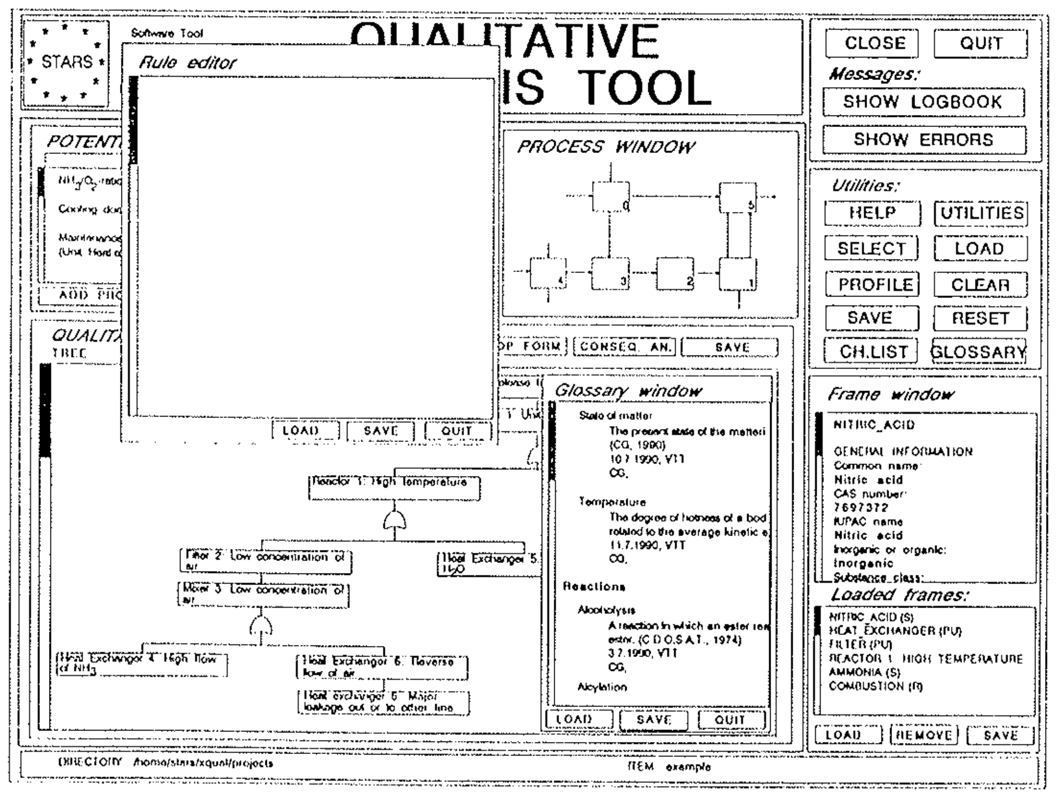
The STARS qualitative analysis tool supports the user of STARS in identifying potential hazards at the process plant under investigation.

The purpose of the qualitative analysis tool is to identify and fix the order of priorities of those hazards to be subjected to further analysis, i.e. construction and analysis of fault trees and assessment of consequences (estimates of concentrations of toxic substances, heat radiation levels, etc.).

Three methods are supported by the program and can be used separately or combined in the qualitative analysis. These are:

- free or inspired idea processing
- interactive knowledge-supported construction of event sequences
- use of checklists, guideword lists, and data bases of previous analyses and experiences.

Figure 2.1. User interface for the qualitative analysis



Knowledge bases are used in the interactive knowledge-supported construction of event sequences leading to hazards. These knowledge bases are described in detail below.

STARS contains five knowledge bases: one for chemical substances, one for chemical reactions, another for predicting unwanted chemical reactions, a fourth for plant/units, and finally one for components. The knowledge bases along with the inference engine and a user interface form the expert system of STARS.

When the construction of event sequences in the qualitative analysis part of STARS is carried out, the three chemical knowledge bases are inspected as the first step of the analytical process for possible hazards. Each base is consulted in order to evaluate if certain generic hazards (e.g. fire) are possible, and if so the conditions (e.g. the high-temperature deviation) for the hazard to occur will appear.

The next step in the analysis is to propagate the deviation through the plant in order to identify the final causes of the hazard. This propagation is carried out by making use of the information in the plant/unit knowledge base.

The chemical substance knowledge base contains a data base that describes the physical, chemical, and toxicological properties of the substances and their potential hazards. The chemical reaction knowledge base contains rules which relate specific classes to the generic hazards and the conditions for the hazards to occur.

The purpose of the unwanted chemical reaction knowledge base is to make it possible to evaluate whether or not an unwanted mixing of chemical substances can cause hazards. The evaluation is based on a reaction matrix. All possible combinations of substances will be considered to ascertain whether any of them can give rise to a hazard; it is then determined whether such combinations are possible within the actual plant configuration.

The plant/unit knowledge base contains plant and unit specific information. In the plant frame, information that is specific for the plant is given. This includes the name, plant topology, block diagram, and which raw chemicals are present and their amount. For the unit frame, information that is specific for the unit is given. This includes, the name, type, substances in the unit, inputs, outputs, capacity of the unit, and the maximum and minimum temperatures.

Furthermore, the knowledge base consists of a set of rules for identifying potential consequences of different process conditions and deviations in different units, and another set for propagating process deviations through the process plant.

The prototype version of the qualitative analysis module will be completed in 1991. The termination date for the project is 1992.

2.1.2. Terotechnology

Two projects within the Nordic Tero programme were completed in 1990. The main idea behind the projects was to develop a software tool for improving operation and maintenance planning by supervising the current reliability state of the plant and its components, and to use this information to set up a decision support system (DSS) for maintenance planners.

In addition, a differentiated user interface will serve several members of the organizational hierarchy, such as managers, operational staff, and maintenance workers with information and advice suited to their specific needs.

The program is built around a set of reliability analysis models for specially selected events for the plant in question. A number of different types of information flow in such a system:

- measured values of parameters influencing component and plant reliability
- failure and repair reports input by the staff
- results of statistical calculations
- requests for calculations or other information
- results of calculations with a reliability model of the plant
- advice from the decision support system
- operational and maintenance strategies.

The various types of information need different ways to process and present data. Data measured in the plant will have to be preprocessed and evaluated before they can be used for assessing the change in reliability. It is envisaged that an "expert system" will be utilized for this task. Most of the information types mentioned above will, however, involve communication with the human operator. Therefore, a key aspect of the project is the creation of interfaces which ensure an easy exchange of information. The system concept is shown in Figure 2.2.

The condition of a component can be monitored by measuring values of specific parameters with a subsequent comparison with expected values. An example is shown in Figure 2.3.

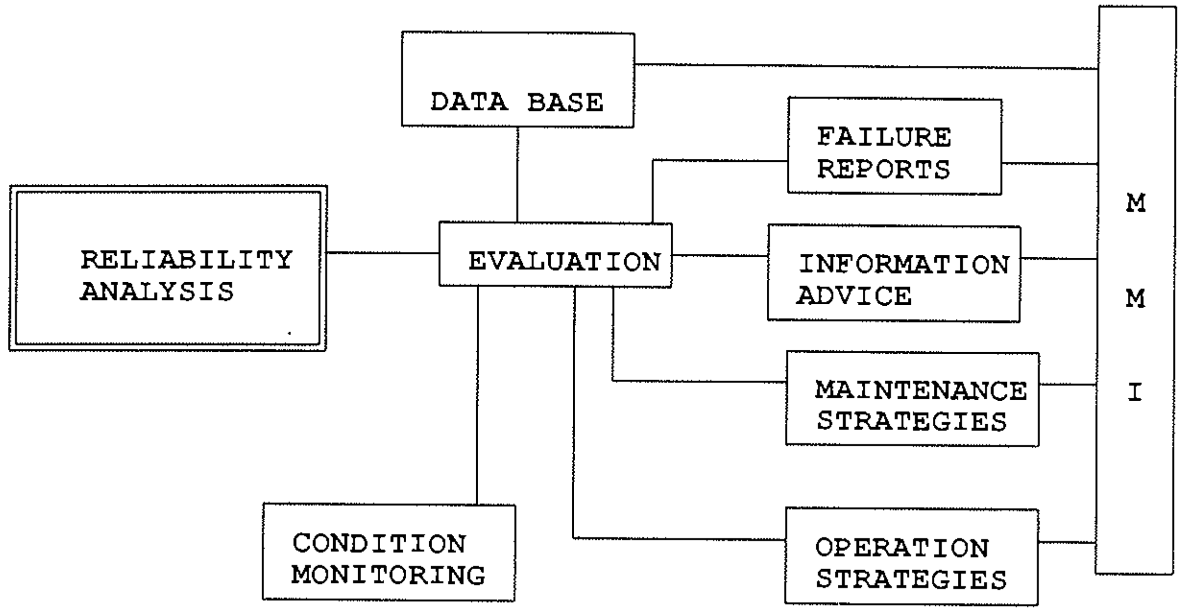
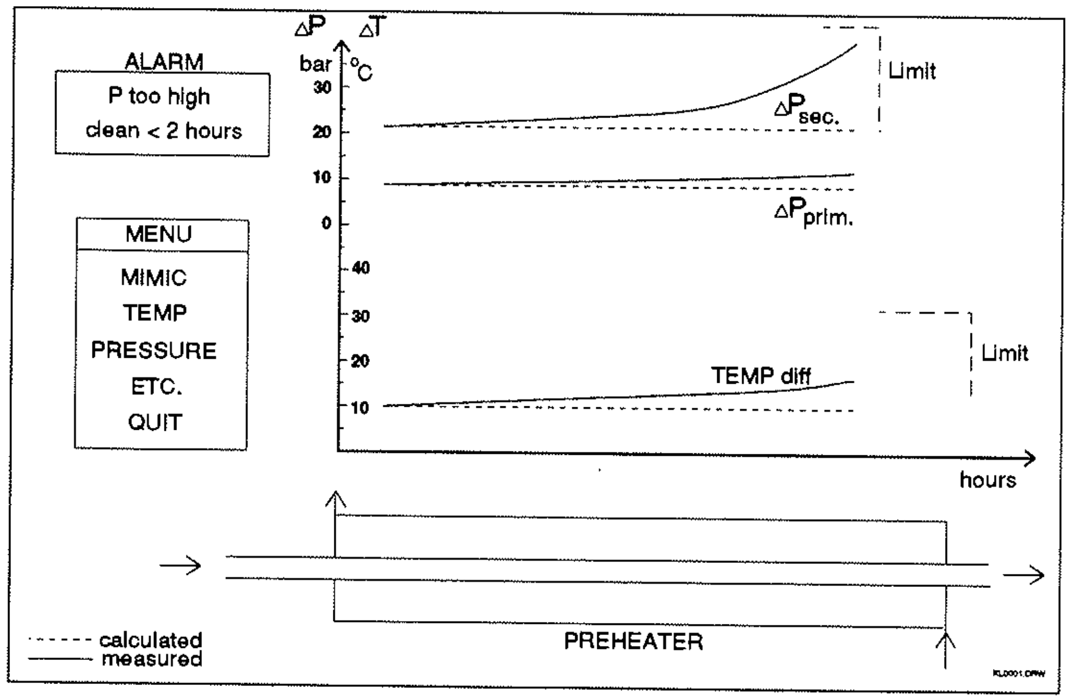


Figure 2.2. System concept.

Figure 2.3. Comparison of calculated and measured temperature and pressure differences in a preheater.



2.1.3. A Practical Tool for Reducing the Occupational Accident Rate

The number of reported occupational accidents in Denmark increased by 33% during the period 1983-1986. In 1986 more than 28.000 accidents occurred in Danish industry corresponding to an overall accident rate of 23 accidents per 1000 employees.

Experience from the oil industry in Denmark as well as abroad shows that systematic efforts to reduce accidents have met with success, drastically reducing the occupational accident rate.

Supported by the oil industry evidence, Danish Industries Employers Federation initiated the development of a practical guide for making risk analyses of occupational processes. The project was sponsored by the insurance company "J.U. Forsikring limited".

The purpose of the guide is to identify the most essential occupational hazards in Danish industrial companies. This would enable the most efficient measures for reducing the occupational accident rate to be put into effect.

The guide was developed on the basis of experience gained from the risk analysis of three industrial occupational processes. It will be communicated to the users by means of following three publications:

1. HOW? the procedure
2. WHY? background and method description
3. THIS WAY example.

Publication no. 1 HOW? is a very short and handy document designed for practical applications by safety personnel. It contains a short description of the procedure incorporating many features similar to a HAZOP analysis and consisting of the following four steps:

STEP 1: Occupational processes which have been hit by accidents or near misses or which have potentials for accidents are identified.

STEP 2: A safety review panel for each of the activities identified in step 1 is established.

STEP 3: Danger-zones are clearly marked on photos or drawings.

STEP 4: All of the occupational activities are reviewed one by one. For each of the possible accidents, proposals for necessary precautions to be taken are identified. Whenever necessary, supplementary analyses are recommended.

Publication no.2 WHY? describes the background for risk analyses of occupational processes with appropriate references.

Publication no.3. THIS WAY contains an example of a detailed risk analysis of an operation on a universal milling machine.

The publications will be distributed to two different industrial companies for a final trial in the beginning of 1991. Afterwards, the publications may be modified in accordance with the experience gained from practice.

2.1.4. Reliability Analysis of the Great Belt Link

For DSB Danish State Railways a project was initiated in 1990 to develop a reliability analysis of the technical installations in the Great Belt Link, which is under construction between Zealand and Funen.

The project forms part of the efforts towards assuring that the comprehensive technical equipment operates with sufficient operational safety to prevent disturbances in the train traffic flow patterns.

The reliability analysis comprises the following systems:

- instrumentation and control
- power supply
- catenary system
- mechanical installations (e.g. pumps and ventilators)
- signalling and block system
- safety systems and section block
- radio and remote control
- railway track system

The project is divided into three phases:

Phase I was carried out in the middle of 1990; it comprised the reliability requirements in the tender design material for the individual components and units.

Phase II concerned a qualitative systems analysis. All the systems were reviewed with respect to their reliability and possible influence on the train traffic due to equipment failures. An overall reliability model, mainly comprising the power supply system, was established.

Phase III will be carried out in the beginning of 1991 and will comprise the quantitative calculations primarily by means of the programs SIMON and FAUNET, developed by Risø. The calculations will include estimates of the mean time between failures, MTBF, that cause stoppages of the train traffic in one or both of the tunnels. All repairs of equipment in the tunnels will require that train traffic in one of the tunnels

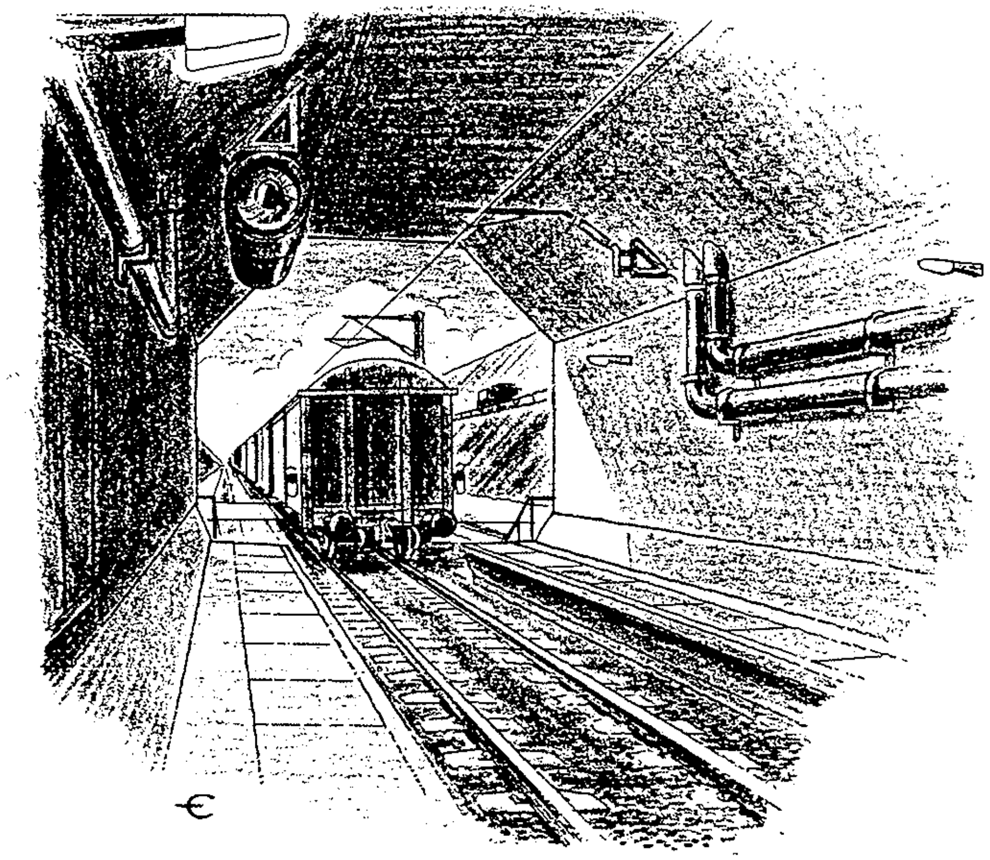


Figure 2.4. The railway tunnel between Zealand and Sprogø near the eastern end (Drawing by Erling Nederland, courtesy of DSB).

be interrupted to secure the safety of the personnel. Certain equipment failures do not require immediate interruption of the train traffic, and the work can be postponed until night-time when all the train traffic can be diverted into a single tunnel; this would not be expected to cause delays as the traffic density would be low.

The qualitative and quantitative reliability analyses may very well give rise to suggestions for changes at component or subsystem levels in order to bring equipment reliability up to an acceptable level.

2.2. Consequence Modelling

The activities are focused on evaluating the consequences of accidents at industrial plants. The work comprises theoretical as well as experimental studies.

In 1990 work was concentrated on three areas:

- experimental work on torch fires where released medium pressure natural gas is ignited and flame characteristics are measured in field test experiments,
- experimental work on combustion of chemical substances originating from warehouse fires based on laboratory tests to identify toxic substances generated during a fire. As a supplement a new Ph.D. study was initated with the focus on the final toxicological effects from dispersion of the toxic substances,
- model validation for two-phase outflow from a pipe. Experiments were carried out some years ago and the results were compared with other experiments and model predictions.

A number of models intended for calculating the release and dispersion of gases were developed and implemented on a PC and have been applied in a couple of practical studies for Danish industry.

2.2.1. Torch Fires

The Torch Fire project is a subproject under the CEC research programme on major technological hazards. The aim of the project is the theoretical and experimental investigation of gas jet flames and their impact on obstructing structures. The work is done in collaboration with groups from other European countries working with flame modelling and/or wind tunnel experiments. Risø's task is to carry out large scale experiments.

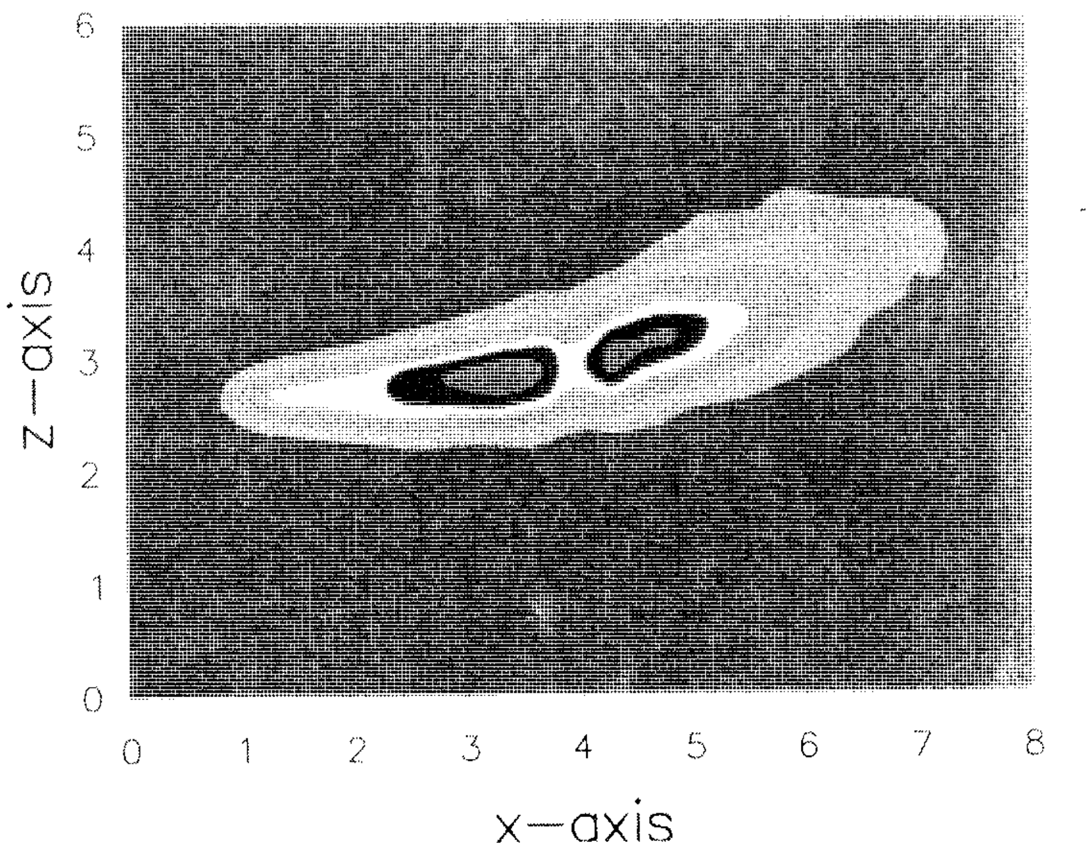
A test facility has been constructed at Risø, where equipment is available to produce large jet flames or "torch fires" using natural gas as fuel. The burner produces a vertical flame up to 8 metres long. The site also has a meteorological mast equipped with cup anemometers, a wind vane, and an ultrasonic anemometer. Two computers located in a caravan take care of the acquisition of data from the meteorological instruments and from thermometers, radiometers, gas flowmeter, etc. In this work the Systems Analysis Department has received support from the Departments of Meteorology, Combustion Research, Electronics, and what was formerly Mechanical Systems. The Technical University of Denmark has been helpful in supplying certain equipment on loan.

During 1990 the first series of experiments was performed. This involved measuring temperatures in a free flame extending along the wind as well as the shape of the flame with an infrared-sensitive video camera. Ten successful experiments were completed with varying gas-release rates and different wind speeds. In the near future the results will be compared to theoretical predictions and to small-scale wind tunnel tests. One of the objectives is to confirm the applicability of certain scaling relations, in other words to see whether small flames behave like large ones.

The infrared video recordings were digitized and processed on a computer. In this way an analysis can be made to extract a characteristic shape which can be compared to theoretical models. One problem that occurs is that current theory takes no account of large-scale fluctuations of the flame. These fluctuations are due mainly to atmospheric turbulence, a random phenomenon. Thus, one cannot predict in detail the individual eddies that deform the flame.

Random motions of the flame also affect the reading of stationary sensors, so arrays of sensors have to be used in order to distinguish the fluctuations caused by the shifting of the position of the flame from the "intrinsic" fluctuations caused, for example, by dynamic instabilities. Thus, if one wishes to measure the temperature in the centre of the flame, several thermometers are needed to establish the actual position of the centre. In the same way the flame shape on a particular infrared snapshot will not be predictable, so averages have to be made.

Figure 2.5. Measured average infrared intensities in a natural gas flame.



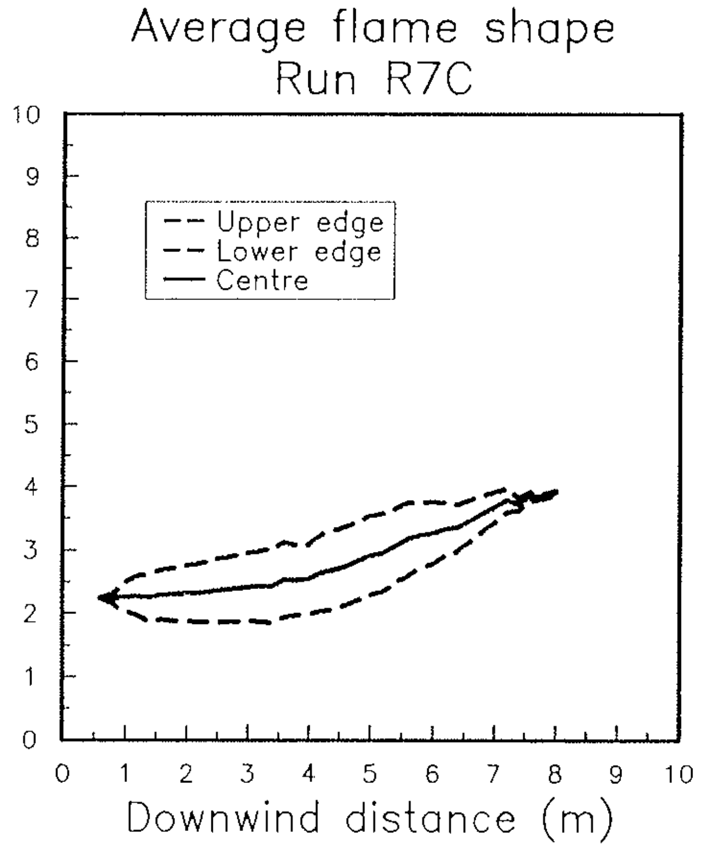


Figure 2.6. Analyzed shape of natural gas flame made by means of digital image processing of infrared video.

Figure 2.5 shows an image made simply by point-by-point averaging the intensities of 32 individual images taken over a period of about 3 minutes. The picture looks much more regular than the ones it was made from, and thus it might have been predicted from flame theory and atmospheric turbulence statistics. In the middle, 4 metres downstream, the intensity decreases; this is caused by a mast that has been placed within the flame and obscures part of the picture. The picture displays an envelope within which the flame moves about, as well as a core which is generally hot, but it fails to give a good representation of the shape of the flame. The actual shape is more like a wiggling banana than a cone bending upward. Figure 2.6 is a different representation of the same 32 images. At 64 positions downstream of the outlet nozzle, the width of the flame and vertical position of the hottest spot has been measured on each image. From these data an average centreline can be computed along with the varying width. In other words, Figure 2.6 represents the average banana shape, leaving its wiggling movement out, analogous to the way flames are conceived in present-day modelling.

In a second series of experiments, radiational and convective heat transfer to an object was measured.

2.2.2. Combustion of Chemical Substances

Each year a large number of fires occur at chemical installations all over the world. In a great deal of these fires storage facilities with large amounts of chemical substances are involved.

When the risks from chemical storage, such as in the case of pesticide storage, are to be assessed, many problems in connection with the fire arise. The most important are identification and quantification of the toxic fire products.

In 1990 a combustion furnace for laboratory-scale experiments has been constructed and some experiments have been carried out. The furnace consists of a quartz tube enclosed by a heating element. The temperature can be fixed (300°C-800°C). 500 mg of the chemical substance are placed in a sample boat in the middle of the tube; the chemical is then decomposed with a fixed air flow through the tube. The combustion gases are collected in an appropriate solvent and analysed by titration or combined gas chromatography and mass spectrometry.

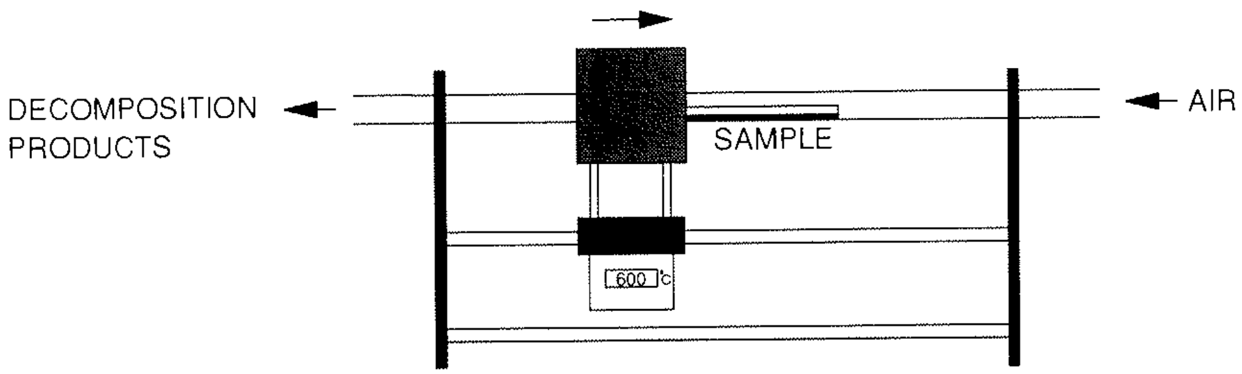


Figure 2.7. Design of combustion furnace according to DIN 53 436.

In 1990 a Ph.D. Study entitled "Toxic Products in Smoke from Chemical Fires" was initiated. The aim of the project is to establish methods and acquire apparatus to investigate pyrolysis and combustion products of some selected chemicals and the toxic effect of the smoke on animals. The results should be used to predict the toxic hazards to humans of the fire effluents from these chemicals.

It has been decided that the experiments will be performed according to DIN 53 436. The chemicals chosen for decomposition are chlorinated pesticides. These pesticides, which are all commercially available in Denmark, are chosen because they might produce highly toxic gases such as HCl, COCl2 and/or PCBs, and dioxins. The chemicals will be pyrolysed or burned under controlled conditions including air flow, temperature, with or without ignition, etc. The decomposition products and what is left of the original compound in the smoke will be quantitatively and qualitatively analysed.

The next part of the project will be toxicological inhalation studies. Animals will be exposed to the decomposition products of a selected chemical substance investigated in the first part. Some of the factors to be considered in the animal based inhalation studies are exposure time, decomposition conditions, which bioassays to be performed during and after exposure (respiratory rate and other pathological examinations), endpoint criteria, etc. Analyses of the decomposition products are necessary even in this part of the project. This will be done to obtain information on the exact composition of the smoke to which the animals are exposed.

The Ph.D. study is planned to be completed in 1993.

2.2.3. Validation of Two-Phase Outflow Model

Important parameters related to releases of material from the rupture of pipes that carry liquified toxic or flammable gases are often calculated by means of a homogeneous two-phase flow model. Release rates predicted by a model of this type have been compared with experimental results from a blowdown facility where superheated water in a vessel was released from the liquid phase via a 2-m long pipe (Figure 2.8).

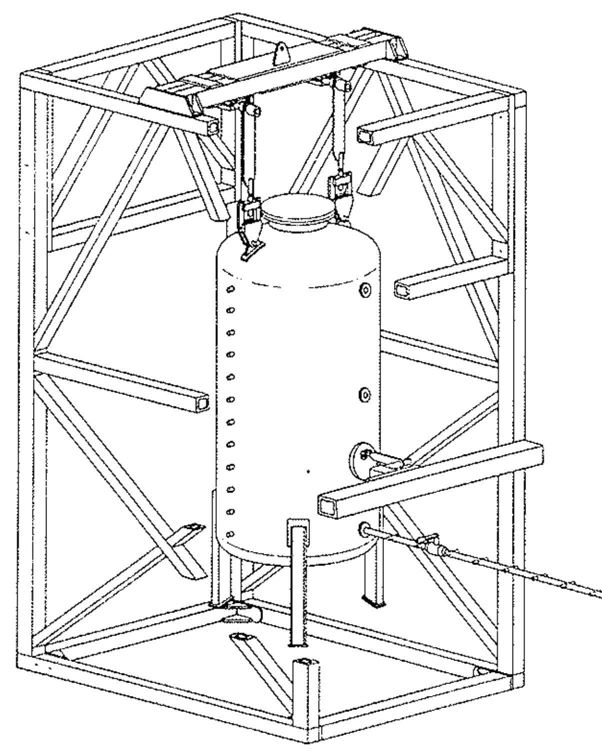


Figure 2.8. The experimental facility. Total volume of pressure vessel, 2 m^3.

The blowdowns were performed some years ago in connection with a Ph.D. study of flow phenomena during a water blowdown. The blowdowns were performed with the initial pressure in the vessel ranging from 4 to 10 bar and with pipes having diameters of 10 mm, 33 mm, and 80 mm.

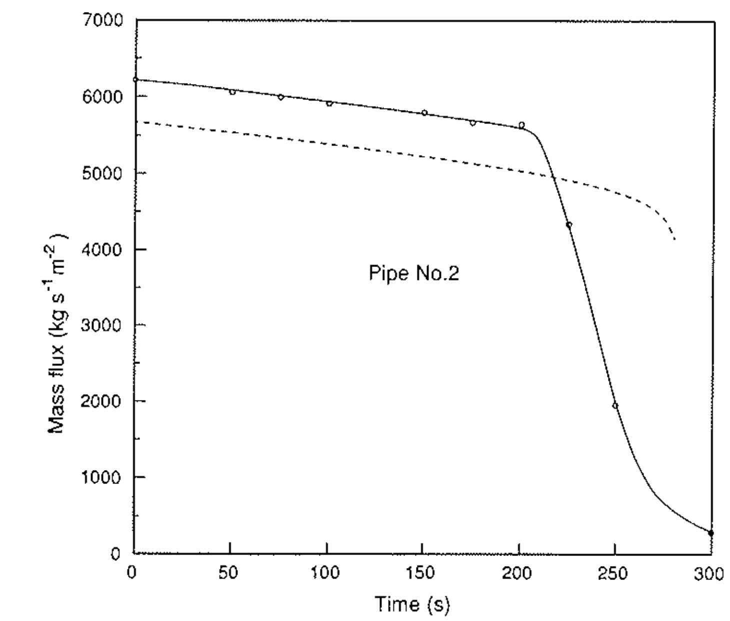
The model considered has been developed primarily for use in industrial risk analysis. Apart from geometrical data, the input parameters of the model are the relevant thermodynamic and physical parameters as functions of temperature, the wall roughness of the pipe, and the resistance coefficient of the pipe inlet.

On the basis of the comparison of predicted and measured flow rates, and of model studies (parametric studies), conditions for obtaining predictions with good accuracy are identified. The maximum error of the predicted mass flow rate is about 10% when the following conditions are met:

a) the liquid viscosity is close to that of water,
b) the pipe diameter ≥ 10 mm,
c) 3 ≤ (length of pipe)/(pipe diameter) ≤ 175 F where the factor F is dependent on the pipe diameter and its roughness, and
d) the flow is a critical two-phase flow (the model indicates itself whether this condition is met).

For materials and pipes which meet the above conditions, a blowdown transient can be described with good accuracy by applying the basic two-phase flow model together with a model for the temperature drop in the vessel. An example of measured and predicted mass flux versus time is shown in Figure 2.9.

Figure 2.9. Measured and predicted mass flux versus time during blowdown. Initial value of hydrostatic head: 0.132 bar. Initial value of vessel temperature: 176°C. (○ measured; --- predicted).



2.3. Risk Management

The activities are carried out with the aim of developing guidelines for assuring the safety of an industrial plant during the design phase, both during normal operation and emergencies.

In 1990 work was concentrated on two areas:

- developing a method for assessing the environmental and occupational effect of new materials to facilitate a complete life-cycle analysis of materials.
- developing guidelines for the contents of risk analyses and establishing of acceptance criteria for harmonizing the practices within the Nordic countries.

Further, a project was finalized on developing educational material on risk, risk analysis, and risk evaluation with the aim of encouraging more balanced discussions when risks are estimated and compared.

In 1990 two new initiatives were launched. The first is a Nordic project on establishing of a system of indicators for safety, performance or maintainability. The work is a continuation of the Nordic research work carried out in 1985-90. The main effort will be put into defining maintenance indicators to be used in reliability-centred maintenance planning. Secondly, preliminary work has begun on developing an integrated risk manager model taking into account the risks, economic losses from accidents, and insurance aspects. The work will require close cooperation with industry and insurance companies.

2.3.1. Integrated Assessment of Environmental and Work Environmental Effects of New Materials

The project was initiated by the Danish National Agency for Industry and Trade. The aim of this preliminary study was to create a tool which can help material developers in their efforts to minimize or totally avoid unwanted environmental and health effects from new materials. The project was carried out by five institutions in cooperation: Danish Technological Institute, Risø National Laboratory, Technical University of Denmark, Odense University, and Danish Environmental Research Institute.

The main result of the project is a screening procedure which can be carried out by constructors, designers or technicians. The screening procedure focuses on physical and chemical properties, health effects (acute and chronic toxicity, irritation, sensitization, neurotoxicity, organ toxicity, reproductory toxicity, and carcinogenicity) and environmental effects (toxicity, bioaccumulation, biodegradation, and bioavailability). Suggestions for decision making on the background of the screening are given.

The method can be used as a platform for further developments in the material assessment field. The project identified some problem areas where additional research and development is necessary in order to be able to make a complete life-cycle analysis of materials.

2.3.2. Developing and Testing Guidelines for Risk Analysis

This project is a Nordic co-operative project which was initiated in 1990 and is planned to be finished in 1992. The project is financed by the Nordic Council of Ministers and the work is carried out by Risø National Laboratory, the Technical Research Centre of Finland (VTT), and SINTEF from Norway.

The primary purpose of the project is to develop and test practical guidelines for preparing a risk analysis and criteria for evaluating the acceptability of the risks. It is intended that the guidelines and acceptability criteria should be tested in Nordic countries in cooperation with industry and authorities.

In the first part of the project, legislation and current practices concerning major hazardous industries in Nordic countries and in some EC-countries were studied. The focus was on how different countries apply the CEC Risk Directive, usually known as the Seveso Directive, on major accident hazards of certain industrial activities. In addition, the first part of the project comprised a description of some existing and proposed criteria for acceptability of risks from offshore activities and the nuclear and chemical industries.

An initial version of the guidelines for the content of a risk analysis has also been developed. In the next phase of the project, these guidelines will be discussed with the authorities and tested on selected test plants. Finally, the guidelines will be revised.

2.3.3. Educational Material

A project started early 1989 was nearing completion at the end of 1990.It involves the development of educational material on risk, risk analysis, and risk evaluation, and is being carried out under contract with the Danish Academy for Technical Sciences. The aim is to present a comprehensive set including texts, problems, and a series of slides for illustration to be used in upper school classes, high school, and study groups, where people are looking into everyday risks, the way that society deals with risks, industrial risks, etc.

Experience with the testing in high schools shows that the study of problems involving risk management evokes an enthusiastic response: estimating and comparing risks and choosing which risks to take with limited resources at hand.

The project output includes:

* Seven text modules treating the following topics:
  - life's risks
  - incidents and accidents
  - risk measurement and risk analysis
  - the human factor
  - public control of risk, acceptance criteria
  - citizen and risk in society
  - ammonia production, storage and handling
* Twelve problems on risk calculation, risk evaluation and risk ranking
* A series of 130 slides concerning direct illustrations of subject matter, as well as examples from history and art.

3. Cognitive Systems Group

Information technology is presently changing human work conditions in several ways: by (1) increasing the level of mechanization and automation, (2) serving planning and control of integrated manufacturing systems, (3) accommodating the demands on flexibility posed by modern business environments, and (4) integrating the operation of large and distributed organizations. Tasks in these dynamic, cooperative work settings are discretionary and involve human cognitive processes such as problem solving and decision making. To fully take advantage of the potential of advanced information technology, it is necessary to (1) explore the structure of the work domain concerned, (2) define resource envelopes needed by the users to apply their preferred mental strategies successfully, and (3) analyse how the information required should be presented in order to match the perspective adopted by the users during their work.

These are the basic research issues in the Cognitive Systems Group, whose activity is directed towards (1) Cognitive Systems Design, (2) Cognitive Modelling, and (3) Risk Management (in co-operation with the Risk Analysis Group). *Cognitive Systems Design* is regarded as the process of combining analyses of work domains and human tasks with the testing and validating of the utility of interface designs based on an 'ecological' view on human perception. *Cognitive Modelling* entails creating descriptive models of knowledge structures and human perception-action loops, and using such models to explain adaptive behaviour shown by human subjects in laboratory experiments with simulated work domains and skill-demanding tasks. The effort in relation to *Risk Management* is motivated largely by the need to clarify the design criteria for information systems introduced as a means of avoiding industrial hazards or mitigating the societal and material consequences of system breakdowns and accidents.

3.1. Cognitive Systems Design

The work done in 1990 in relation to Cognitive Systems Design was highly influenced by the Group's participation in MOHAWC – *Models of Human Actions in Work Context* – a CEC ESPRIT-2 Basic Research Action started in 1989. MOHAWC is coordinated by Professor Jens Rasmussen and has leading university researchers in Manchester, Liège, Berlin, Paris, Toulouse, Uppsala, and Roskilde as partners. The CEC Joint Research Centre Ispra is associated with the project. This collaborative effort is envisaged to become a major incentive for the European information industry to adopt a cognitive view of systems design. An important ingredient of MOHAWC is a series of four topical workskops; two were held in 1990 and the others are planned for 1991.

3.1.1. Taxonomy for Cognitive Work Analysis

As one of its contributions to the MOHAWC project the Group has developed a *Taxonomy for Cognitive Work Analysis*. This development should be conceived as an outline of a theory and a classification of the rich variety of human-system interactions in complex work environments. It constitutes a multi-faceted framework for analysing means-ends relations in work domains, work requirements in particular situations, effective strategies to cope with such situations, competences and cognitive resources of individuals depending on their education and level of expertise, and subjective preferences of individuals having different aspirations in performing their work. The perspective on human work is much wider than in the various methodologies of Structured Analysis, the methods and schemes of office analysis and requirements specification, and Knowledge Engineering.

A pervasive notion in the Taxonomy is that there are many possibilities for action in most work environments. In stable environments, however, the options to do things in different and perhaps more efficient ways are rarely exploited. Many alternatives for action are neglected due to the individual actors' professional attitudes and habits as well as the practices and traditions of the company. This neglect makes it difficult for managers to explore adequately how to restructure their businesses to achieve a maximum benefit from advanced information technology. For example, the Office Automation experience has demonstrated that the advantages of information technology in terms of increased productivity, flexibility, product quality, etc., cannot be obtained without a corresponding change in the way the work is organized. New technology means new ways of doing things.

Cognitive work analysis serves to pinpoint the options for change and to prepare the ground for optimal absorption of new means for action within an organization. This is accomplished by identifying the basic company goals and constraints, the relationships among goals, functions, and processes, the criteria available for allocating roles to individual agents, and the coordination needed to attain an optimal work organization and management structure. In dynamic environments the first and most important requirement in performing a task efficiently is to explore all available alternatives for action, and then choose the one that best leads to the desired goal with the minimum expenditure of cost and effort. This means that it is especially important to disclose the *possible* means-ends relations between the constituents of the work domain.

The Taxonomy is in particular intended to serve the following purposes:

1. To integrate and develop cross-disciplinary research theories and methodologies for cognitive work analysis in modern, complex work domains. The view here is to provide researchers of cooperative work settings and information system designers with a common language for the description and classification of work domains in terms of their prototypical features.
2. To establish a methodology for functional specification and design of integrated multimedia information systems, and to enable planners of such systems to predict the behaviours expected of individuals and organizations in response to changes in work conditions.
3. To establish a methodological tool for planning field studies and data collection in various, actual work domains, and provide a means for consistent analysis of collected empirical data in order to express results obtained from work studies.
4. To enable comparisons to be made of different work settings with respect to behaviour-shaping features. This has a two-fold purpose: to support the generalization of results from particular work studies, and enable system designers to transfer results from an analysis made in one work domain for use in planning and evaluating information systems for other domains. This cross-disciplinary aspect is furthermore relevant for transferring research results from controlled laboratory experiments to real working situations.
5. To serve as a method for evaluating information systems and studying behaviours shown by individual users and organizations for whom the systems are designed, and to facilitate explanatory analyses when discrepancies are observed between what is intended in the design of a system and its actual use.

The structure of the Taxonomy has been drawn up to provide, on one hand, a general representation of a socio-technical system and its

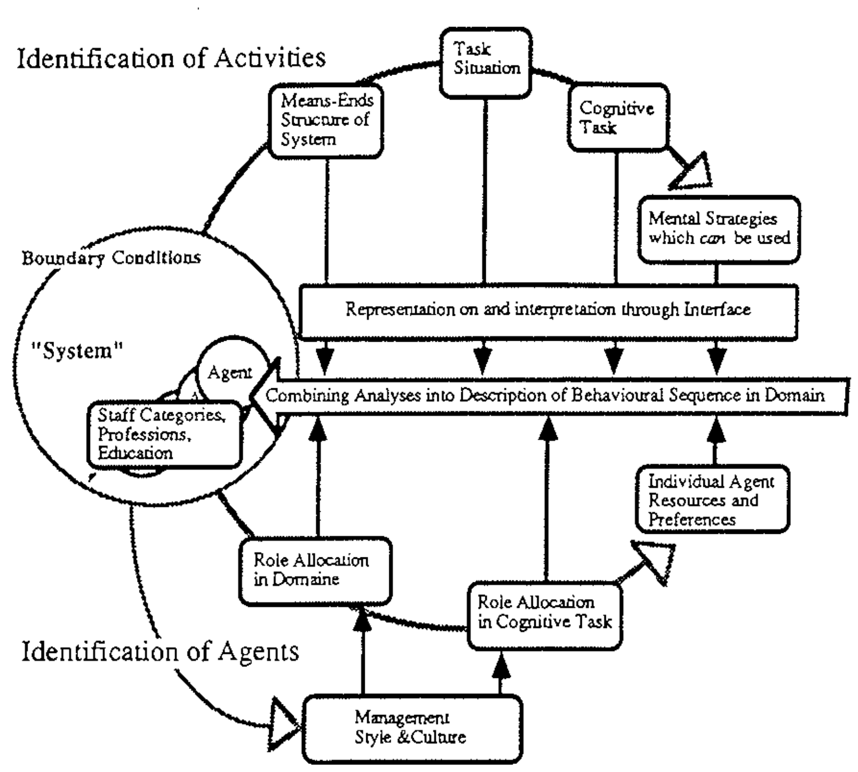


Figure 3.1. Representation of the steps needed to perform cognitive work analysis in an organization.

interaction with the surrounding dynamic society, and, on the other, the subjective human interpretation of the actual state of affairs in such a system. As indicated in Figure 3.1, using the Taxonomy for analysing work and work performance involves following two paths concurrently. One path serves to identify the cognitive task an agent is faced with in a particular situation, the other concerns the agent's role in the organization as well as his or her individual performance as a system component. These two perspectives correspond to the scientific fields normally termed Human-Computer Interaction (HCI) and Computer-Supported Cooperative Work (CSCW).

3.1.2. Human-Computer Interaction

The Group has started a comprehensive effort to explore how work-domain structures and work requirements can be mapped onto computer interfaces to facilitate human decision making and search for information. In several theoretical studies published in 1990, the Group contributed to an emerging *ecological* view on computer interfaces. This view is rooted in the American psychologist J.J. Gibson's ecological approach to visual perception, according to which many of the objects in everyday human environments represent directly perceivable 'affordances'. A chair, for example, affords 'sitting' independently of the kind of chair and the observer's viewing angle. One principle in ecological interface design is to use computer graphics for generating metaphors that act as 'affordances' by creating associations in the user's mind to well-known objects, situations, and actions. Another principle is to visualize *invariances* embedded in the work domain. Such invariances are systemic, structural features that must be respected by the human agent, either because the action possibilities are constrained by natural laws (as in controlling a thermodynamic process), or because company policies, procedural practices, or legislation impose constraints on the agent's choice of action strategy.

The Group's actual experience with ecologically designed computer interfaces derives from the BOOKHOUSE, a system concept implemented in 1987-88 to provide library users with freedom to navigate within a search space of subject categories and book titles. The system allows such users to single out items of fiction in a vivid, graphic environment (see Figure 3.2) in which metaphors (largely represented by mouse-sensitive *icons*) are used to highlight invariances embedded in a library classification scheme. Numerous visitors to public libraries have been given access to the system. There is clear evidence available to indicate that users of information systems perform better when they are given options to choose among several retrieval strategies. Also, interface icons have proven advantageous for encouraging novices to utilize the action alternatives provided by a complex information system.

In 1990 the BOOKHOUSE experience has been reviewed and communicated to wide circles within the information and library professions. Subsequent work has been done to formulate guidelines for ecological interface design in other domains that have been explored in field studies performed by the Group or have been surveyed through informal cooperation with domain experts and system designers. This effort involved reviewing means-ends relations and prototypical decision situations within public health care, planning for surgery and retrieval of both patient records and medical literature in hospitals, information querying in case handling and public service, using computers for educational purposes in public schools, designing mechanical components and selecting processes in manufacturing, and using teledata and teletext systems.

Work has also been done to describe the semantic and semiotic characteristics of icons for interface use, and to highlight the cultural influences on the perception of messages conveyed by icons. These studies are relevant to current efforts in Europe to develop guidelines for internationally acceptable metaphors and icons.

Personal experience and knowledge as well as cognitive style play major roles in shaping the heuristics that individuals are using to perform their tasks. For this reason information systems for planning and decision support should possess the capability to evolve dynamically in accordance with the competences and preferences developed by the human agents of an organization. Work has been started to evaluate requirements and concepts needed for designing adaptive planning tools and decision aids that incorporate this capability.

Figure 3.2. The room for choice of search strategy. From the left: Search by analogy, browsing pictures, analytical searches, browsing book descriptions. When the user selects a strategy, the system supports the search accordingly by a number of heuristics used to automate many of the manipulations necessary for the performance of data base search along various strategies.

Most of the software used to design the BOOKHOUSE is tailor-made C code embedded in a DOS environment. Therefore, the system cannot easily be expanded with new facilities. In a recently begun effort to introduce flexibility in future developments of a similar kind, the BOOKHOUSE is being re-implemented in a Macintosh environment using two advanced hypertools, *Omnis-5* and *SuperCard*. The long-term plan is to establish a multimedia laboratory in which the Macintosh environment as well as its parallels in the IBM world, Microsoft Windows 3.0 and OS/2, are used as platforms for rapid and resource-saving prototyping and testing of advanced interface and database concepts.

3.1.3. Computer-Supported Cooperative Work

Theoretical studies of cooperative work have been started in relation to basic research on distributed decision making within the MOHAWC project. Common to cooperative work arrangements are the elemental functions of amplifying the capacity of individuals and facilitating the combination of specialized techniques. In addition, cooperative arrangements in complex settings serve to ensure both the mutual critical assessment required in the social construction of knowledge as well as the confrontation and combination of different pertinent perspectives required in distributed decision making.

A set of generic functions and architectures have been identified for conceiving cooperative arrangements as distributed control structures within a loosely coupled system, that is, as emerging formations shaped dynamically by the work requirements and the characteristics of the technical and human resources at hand. In modern dynamic work settings, coordination by means of pre-established schemes of task allocation, procedures, plans, and schedules is being replaced by communicating and propagating decisional criteria within the cooperating ensemble. Cooperative work patterns are accordingly in a state of perennial change and renegotiation. Thus, the design of integrated information systems for domains such as offices and integrated manufacturing is faced with the challenging problem of supporting exchanges of information between decision makers that have a high degree of autonomy in their strategies and conceptualizations.

To widen the outlook on cooperative phenomena, the Group has engaged itself in reviewing ways of modelling adaptation and self-organization within several professional disciplines, including control engineering, nonlinear systems theory, biology, cognitive science, and a recently established cognitive approach to organizational sociology. This effort appears to be properly timed in view of the increasing focus on cognitive phenomena in systems-related research and an ensuing convergence of concepts and approaches.

3.2. Cognitive Modelling

Modelling the way human agents cope with tasks that entail identification of situations, memory retrieval, reasoning, and choice of action strategy is a central issue within the MOHAWC project. Since the beginning of 1990, the Group's efforts in this research field has been further stimulated through its participation in *Representation and Processing of Knowledge* – a national framework programme supported by the Research Council for the Humanities and directed by Research Professor Niels Ole Bernsen of Roskilde University. The other participants in this programme are cognitive scientists at the universities in Roskilde, Aarhus, and Aalborg. The objective is improved understanding of a variety of cognitive phenomena, including visual and linguistic perception, learning, mental representations, and casual reasoning.

3.2.1. Theoretical Framework

Work on methods for exploring and modelling knowledge, and for computer representation of knowledge, has been started to create a theoretical framework for describing knowledge structures in terms of semantic primitives, indexing rules, context descriptors, etc. Such a framework is a prerequisite for designing databases offering the precision, speed, and flexibility demanded in Computer-Supported Cooperative Work.

Work has furthermore been started to formulate principles for computer simulation of human adaptation to work requirements. The cornerstone in these efforts is Professor Jens Rasmussen's SRK modelling framework in which human perception-action loops are regarded as intimately coupled manifestations of skill-based, rule-based, and knowledge-based cognitive control. Skill-based control relates to the activation of highly automated movement patterns. These are acquired by training and adaptation; they are invoked by stored rules for action, and kept in synchronism with the dynamics of the environment by perceptual signs without involving the conscious mind. Rule-based control consists in applying procedural knowledge represented by prescriptions or rules. Novices in a work domain become experts by developing a rich cue-action structure diversified into several levels of abstraction. Knowledge-based control is invoked in ambiguous or unfamiliar situations and involves the creation of mental representations of the task content. Causal reasoning, thought experiments, and iterative goal formulation are typical ingredients in the decision process behind knowledge-based action strategies. This domain is the classic subject of Artificial Intelligence.

The SRK framework has been used to study the structure of simulation models that may explain the findings in the empirical studies mentioned in the following subsection. It is of particular interest to highlight the relation between the adaptation capabilities and error propensities of the human subjects in these studies. These two aspects of cognitive behaviour are intimately connected. Adapting to a navigation space delimited by boundaries of acceptable performance involves exploring these boundaries.

3.2.2. Empirical Studies

The Group has set up an empirical research programme to test and validate models of human-system interactions in specific, illustrative cases. The approach chosen consists in letting subjects control events in simulated, dynamic environments presented on a computer screen. Such an environment may be a 'microworld' that reflects the main characteristics of a real work domain and contains a smaller or greater subset of the possibilities for action within this domain. Experiments with microworlds, and gaining insight into what can be learned from such experiments, have become a focus of intensive research and stimulating discussion in the MOHAWC project. The Taxonomy for Cognitive Work Analysis serves as an instrument to clarify the relation between a microworld and the work setting it represents. One aim is to give an explicit account of behaviour-shaping goals and constraints introduced by the 'cover story' told to subjects before beginning their first trial in a microworld experiment.

In 1990 the Group has developed a new version of a forest fire microworld devised by one of the MOHAWC partners, Professor Berndt Brehmer of Uppsala University. In this experimental setting, subjects face a picture of a forest in which a fire is started early in the trials. The task consists in getting the fire under control and extinguished as quickly as possible by deploying fire-fighting units in the burning zone or around it. It is vital to prevent the fire from reaching an area supposed to house the command centre of the operations. A wind indicator and messages from the fire-fighting units assist the subjects in deciding how to conduct the fire fighting. The new experimental system makes it possible to edit, test, and save highly diversified fire-fighting scenarios for use in coordinated experimentation and exchange of experimental data within the MOHAWC group. To take advantage of the flexibility and expansion possibility offered by an object-oriented programming environment, *Smalltalk* was selected as the language for implementing the system. The latter features a graphic interactive user interface (see Figure 3.3) as well as a playback facility for visual identification of the subjects' responses to prompts for action embedded in the experimental scenarios.

A somewhat different line of empirical research in the Group is directed towards studying elementary processes of human learning and adaptation. It entails observing the outcome of repeated trials made by subjects playing a video game whose action rules are simple, but difficult to accommodate because of their strict timing demands. A Commodore game called 'Gymnastics' was selected for an extensive series of pilot experiments carried out with a view to developing a methodology for extracting useful information from vast amounts of automatically recorded behavioural data. The challenge in this particular game is to make a gymnast perform an elegant vault-over-horse by operating a joystick and land the performer in an upright position. A crucial point is whether or not the player decides to increase the difficulty of the game by including a somersault manoeuvre in the vault. This option represents an interesting possibility for studying a complex adaptation phenomenon, whereas the psychological evidence provided by a certain playing style is irrelevant to the Group's current research objectives.

The data that can be logged with a game of this type are the player's joystick moves and button pushes and their influence on the accumulation of scoring points. Several data-processing techniques have been tested, including advanced statistical methods. It seems quite satisfactory simply to plot learning curves and correlations between event frequencies. Work has been started to build a learning automaton with the capability of reproducing a player's adaptation to some of the requirement in the 'Gymnastics' game, such as hitting the springboard near its edge. So far, a PC emulation of the game has been built that preserves the original Commodore screen graphics.

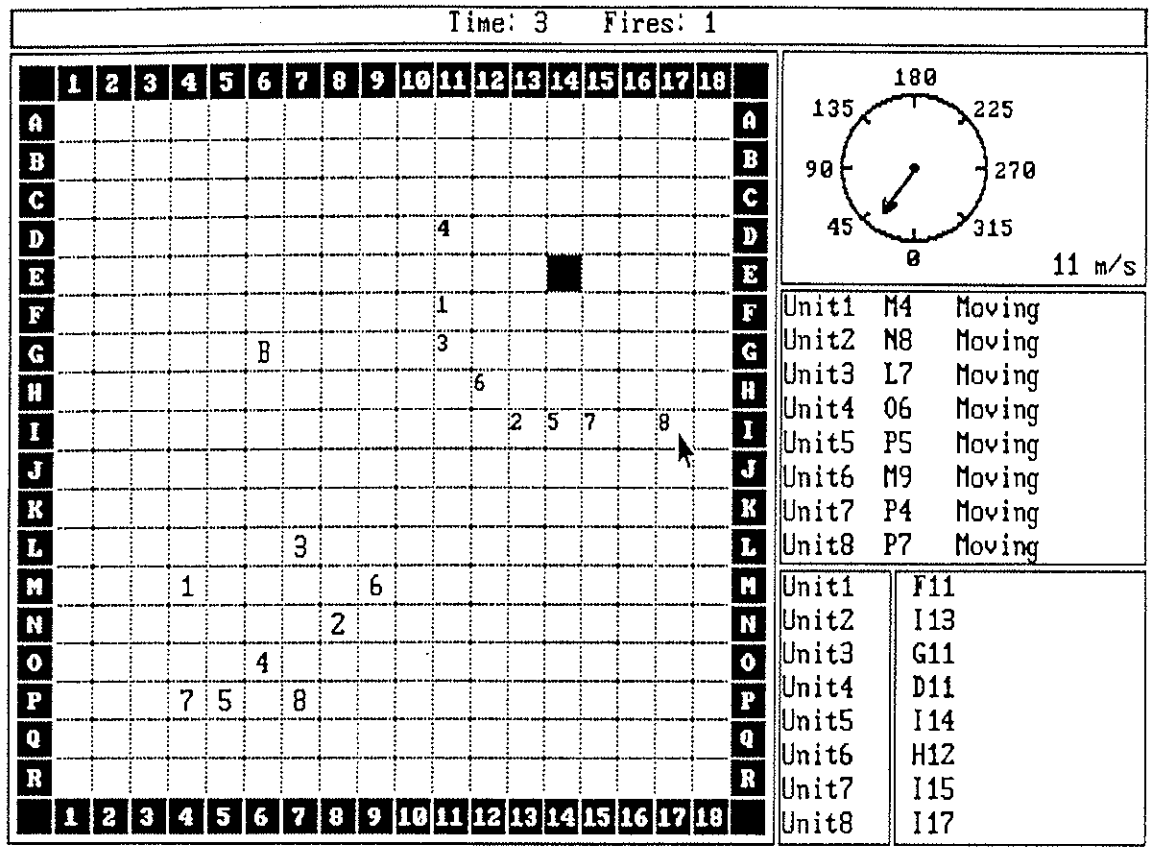


Figure 3.3. Simulated fire-fighting trial performed by a human subject. A forest fire was displayed in cell E14 at time 1. The subject reacted by commanding all of the fire-fighting units (large numbers) to positions on the downwind side of the fire spot (small numbers). The units are on their move towards their destinations. The cell labelled 'B' is supposed to house the command centre (the 'base') of the forest-fire microworld.

3.3. Risk Management

The Group's main effort in relation to computer-supported management of risky or dangerous situations is done within ISEM – *IT Support for Emergency Management* – an ESPRIT-2 action started in 1989. ISEM is coordinated by a senior scientist in the Group, Dr. Verner Andersen. The project has partners in seven European countries. It is carried out as a feasibility and demonstration study focused on the use of advanced information technology for managing on-site and off-site emergencies ensuing from accidents at chemical processing plants and nuclear power stations.

3.3.1. IT Support for Emergency Management – ISEM

The ISEM project is aimed at developing an integrated information system capable of supporting the complex, dynamic distributed decision making in the management of emergencies. Emphasis is put on defining a system architecture and developing an Application Generator and tools to support the full life cycle of the system. The development is driven by requirements derived from on-site and off-site emergency organizations in two different industries, viz. the nuclear and the chemical. Care is taken that the results are easily applicable and adaptable to other organizations.

The Application Generator will be the main overall product of the project. Its functionality is indicated in Figure 3.4, which shows the sequence of development from requirement analy-

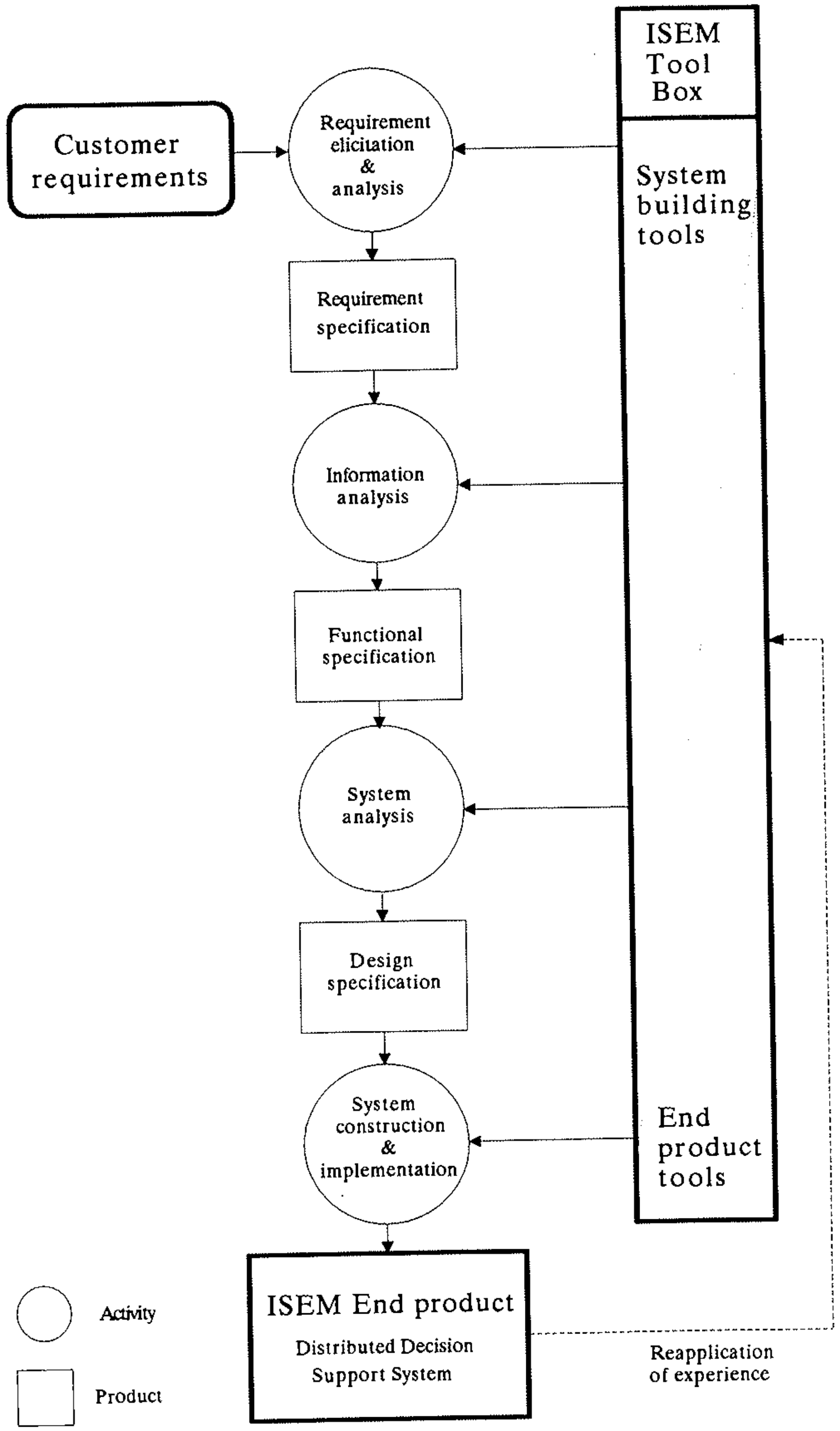


Figure 3.4. Functionality of the application generator developed for the ISEM project.

sis via requirement specifications, functional specifications, and design specifications to the final ISEM end-application. The Application Generator is mainly a tool box that consists of a set of integrated CASE tools. Using these tools it is possible to work at the highest level, identifying the decision support system's requirements and specifications, and store these in a 'Repository' file. Based on this information and on predefined models, a generator produces the programs and interfaces needed by the end-users. Thus, the system is operated at the specification level rather than at source-code level. This philosophy complies perfectly with the purposes of ISEM: development of a generic system (Application Generator) capable of generating two demonstrators using the ISEM tool box.

The supporting functions to be provided in a final application will be defined by the specific end-users of the system. However, based on interviews with end-users and experts, an extensive list of basic functions useful for support of the users in a critical situation has been elaborated. These functions have been merged into a group of composite functions, called functional modules, to be developed as the available end-user support.

A functional module is defined as a module, described in technology independent terms, that provides a given service or a set of functions. The group of basic functions chosen to be developed (see Fig. 3.5) is the following:

- Information Exchange
- Situation Assessment
- Preparedness Plan
- Overview of Activities and Deployment of Resources
- What-if
- Event and Action Log.

The two demonstrator systems, one in Denmark and the other in Spain, will be put into experimental use in early 1992 and will be subject to extensive evaluations. The Group has carried out requirement analysis and final specification of the key part of the Information Exchange module, namely the ISEM electronic Message Management System (MMS) dedicated for use among organizations involved in emergency management. This system, the ISEM MMS, embodies a number of features many of which derive from Risø's long-term studies of human error and cognitive design in high-hazard work environments. At the same time, the specification phase of the ISEM Message Management System has been used as a means of testing key parts of the requirement analysis methodology and the framework for work analysis which has been established partly via the ISEM project and partly on the basis of long-term research in the Group on adaptive system behaviour.

The overall aim which has governed the Group's efforts at developing a full-size prototype of a message management system is, first, to realize ideas about the design of communication support systems derived from Risø's extensive background in the analysis of human work and error and communication in process control environments, and second, to validate, refine and consolidate the requirement analysis methodology (framework for work analysis), which has been established through ISEM as well as the MOHAWC project. In addition to its work on specifying requirements for the MMS, the Group has coordinated requirement specifications for the 'Situation Assessment' and 'Event and Action Log' modules.

The results of this project are expected to be close to final products, and the number of European countries represented makes it possible to make the results available in many countries simultaneously. Furthermore, the composition of the consortium may initiate additional cooperation even after the termination of the project.

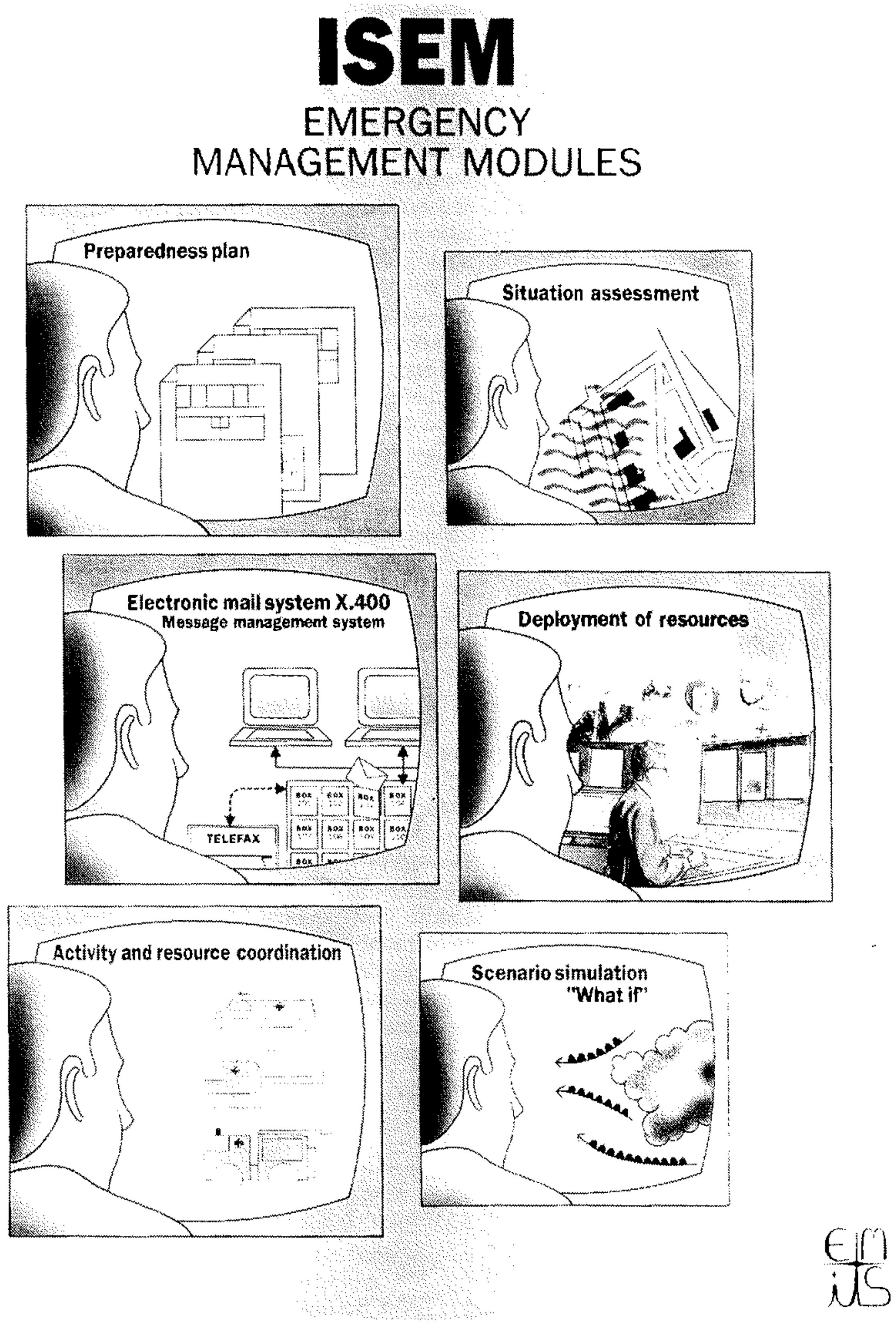


Figure 3.5. Artistic representation of the functional modules.

4. Energy System Analysis

The activities in the Energy Systems Group (ESG) involve energy and environmental modelling and the assessment of energy and environmental technologies.

Within the frame of energy and environmental modelling, the group conducts basic research on the analysis of energy systems, develops tools and methods and applies these to a wide range of problems. The group participates in overall Danish energy planning and the process of establishing the framework for this planning. New models are constructed and used for calculating alternative scenarios. The results are expressed in economic and environmental terms.

Furthermore, the group is currently involved in energy planning activities in third-world countries, and is participating in energy planning projects in Eastern Europe.

In assessing energy and environmental technologies, the group undertakes studies of specific concepts, systems, and technologies. As examples, in 1990 ESG undertook a study of the economics of jointly owned biogas plants, including the construction of a model to calculate the energy, environmental, and agricultural aspects. During 1990 a wind energy planning model was developed as a decision support facility for large-scale utilization of wind energy.

The environmental aspects of energy conversion and use have become an increasingly important part of energy planning and one of the main areas of activity for the group. In 1990 this was reflected in the work of ESG on the new Danish energy plan, "Energy 2000" [1], and reports on emissions of greenhouse gases in Denmark.

4.1. Energy and Environmental Modelling

Modelling the demand and supply of energy and related factors is one of the main research activities of the group. The models are used for planning or analytical purposes both nationally in Denmark and internationally, for example in association with the Commission of the European Communities (CEC) and the Nordic Council of Ministers.

The group has developed and adapted a number of models which can be used to analyse a wide range of energy-related problems. During the energy crises of the 1970s, which were characterized by drastic price increases and energy shortages, the main subjects for concern were their impact on the economy and the security of energy supply. Models were developed to describe the interaction between the economy and the demand and supply of energy, the possibilities for fuel substitution and energy savings, and how to compose and operate an efficient energy supply system.

In recent years the environmental effects of energy production and consumption have become subjects of increasingly concern, and much of the research and modelling effort has been devoted to these areas. Models which include energy-related emissions have been developed, and existing models have been adapted for use in analyses of energy-related emissions.

4.1.1. The HERMES Model

HERMES-DK is a macro-economic medium-term model developed for and used by the CEC. Identically structured national models have been developed for all the EC-countries, and the national models are linked to form a multinational model. The model describes the energy-economy interactions and economic mechanisms of fuel substitution by treating energy as a production factor, as a specific production branch, and as a component of final demand. During 1990 the Danish model was updated and revised, and the first forecasts of overall economic development were produced.

The model has been used to analyse the economic and environmental effects of imposing a tax on CO_2 emission. A feasibility study was carried out in 1990 on the possible extension of the model with a more general environmental sub-model which would include a wide range of environmental effects of economic activity and emissions of pollutants from activities other than the energy sector.

4.1.2. The BRUS Model

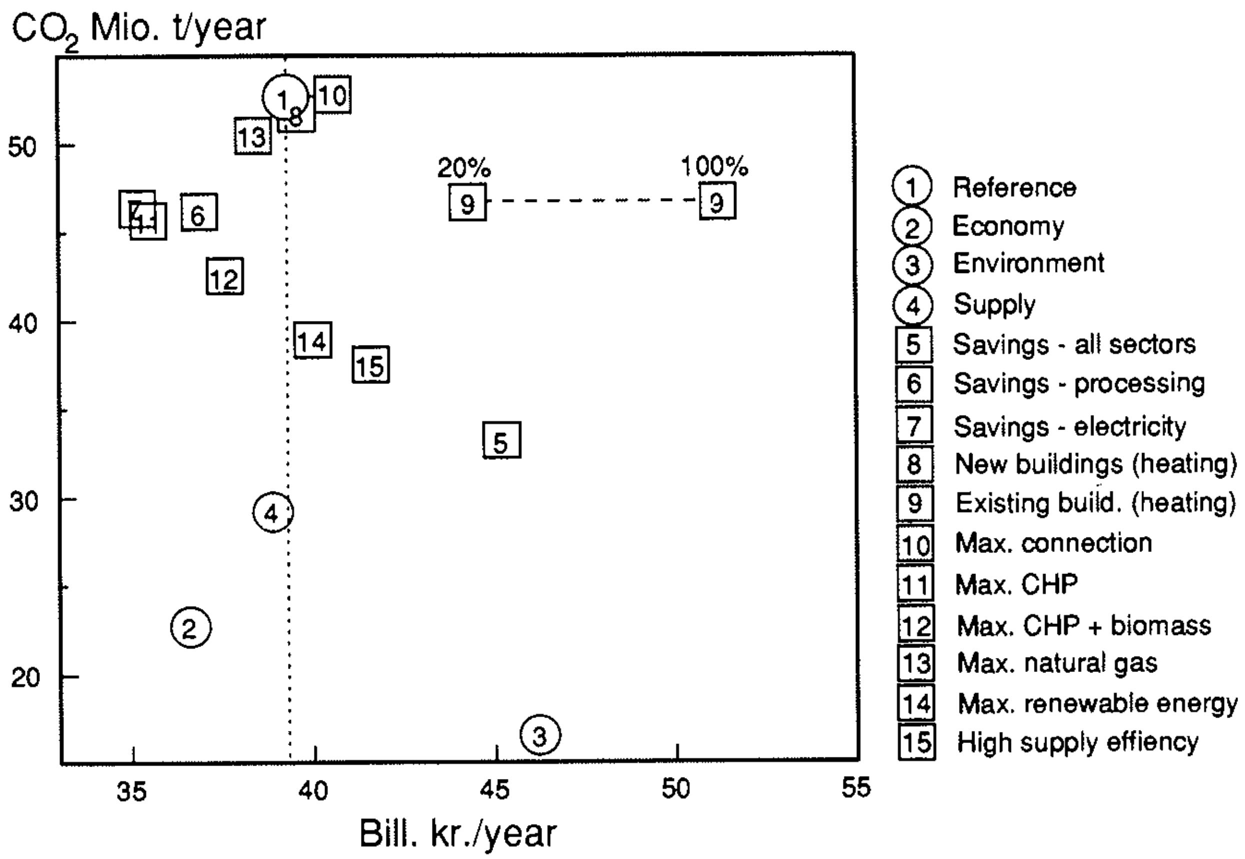
The Brundtland Scenario Model (BRUS) is a long-term simulation model which was constructed for use in the latest Danish energy plan, »Energy 2000« [1]. In the model energy demand and supply are treated in an integrated fashion, allowing demand-driven scenarios for the entire Danish energy system to be calculated. The model data on energy supply and end-use technologies, as well as up-to-date data for emissions of pollutants.

The model was constructed using commercial spreadsheet software and in its details is naturally specific to the Danish case. The methodology and general model structure are however applicable to other national or regional energy systems. The model is described in detail in the Energy 2000 background report no. 7 (in Danish) [2].

Energy 2000 represents part of the Danish government's response to the report of the World Commission on Environment and Development: Our Common Future - commonly known as the Brundtland Report [3]. It thus represents a departure from earlier Danish energy plans in that the effect of energy production and use on the environment is given high priority. In particular, the primary aim of the plan is to reduce emissions of pollutants from the energy system and the effort is focused on CO_2, because of its large production and its association with the greenhouse effect and global warming.

The BRUS model played an essential role in the process by enabling the calculation of consistent scenarios to be made under various sets of assumptions. Figure 4.1 shows the results of a number of scenarios in the form of CO_2 emission plotted against annual energy system cost which includes annual investments, fuel, and operation and maintenance in conversion and end-use technologies.

Figure 4.1 Scenarios for the Danish energy system in 2030, relating annual CO_2 emission to annual system costs.



The three main scenarios considered in the plan were:

1. **The Economy Scenario** – comprising moderate investments in energy conservation, increased use of combined heat and power production (CHP), introduction of combined-cycle power generation, coal gasification, and 1500-MW wind turbine plant capacity.

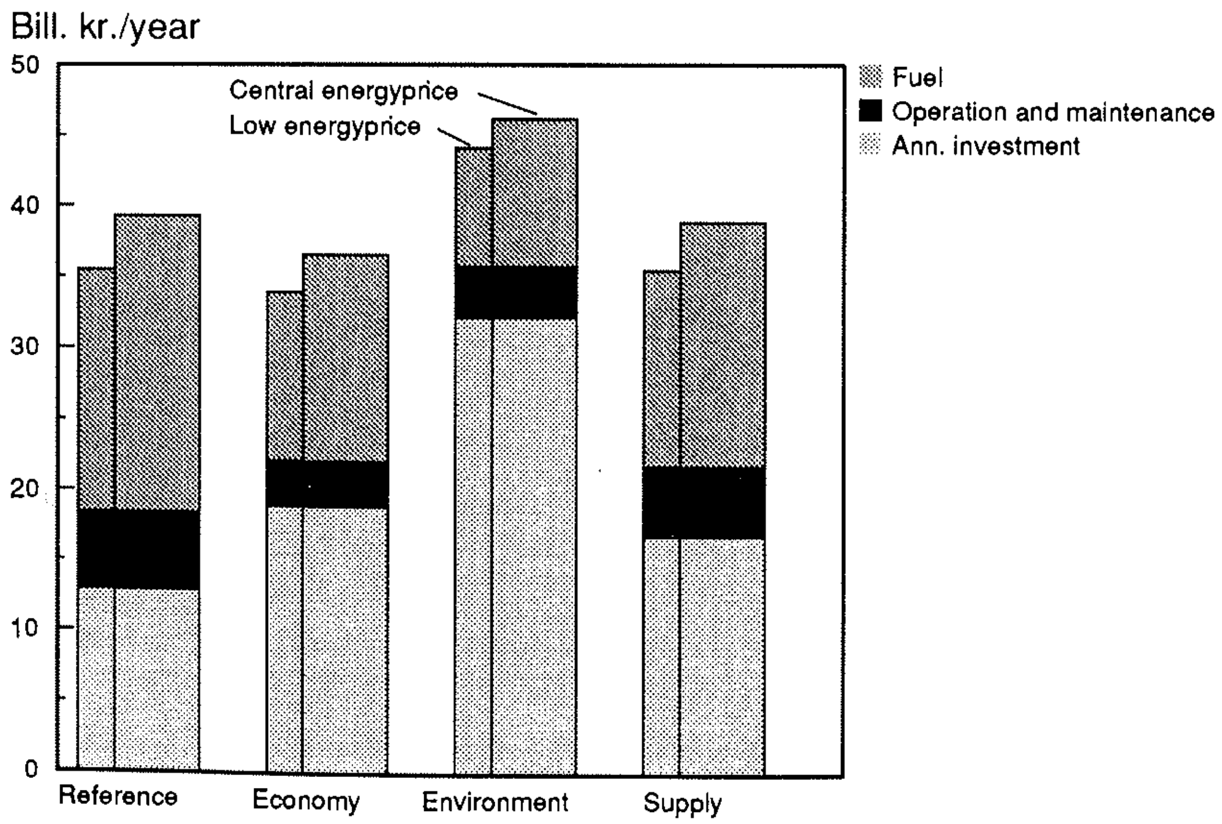
2. **The Environment Scenario** – maximum achievable energy conservation in 2030, increased CHP production, introduction of new technologies such as combined-cycle coal-fired power generation and coal gasification, massive introduction of renewable energy supplies (wind, wave and solar photovoltaic).

3. **The Supply Scenario** – moderate energy conservation, increased CHP production, new conversion technologies such as fuel cells based on natural gas and coal, combined cycle, coal gasification and windpower.

The economic consequences of these three scenarios are shown in Figure 4.2.

The calculations show that it should be possible to reduce CO_2 emissions substantially at relatively little extra cost. In fact, within the uncertainties of the calculation, the system costs are virtually the same. It should be noted, however, that this marked reduction of emissions requires both the introduction of new technologies in the supply system and measures to reduce energy demand while maintaining the same level of energy services. The main reason for this somewhat surprising result is that new energy consuming and conversion equipment, with efficiencies corresponding to the best available at present, is assumed to replace old equipment as the latter is retired. Efficiency improvements in nearly all technologies are also expected to be put into effect throughout the period.

Figure 4.2. Economic consequences of the three main scenarios for central and low energy-price forecasts.



Another important factor which leads to the above reduction of CO_2 emissions at low cost is that the future energy systems represented in the scenarios are calculated on the basis of a projected **reduced demand** for energy, and the supply system is set up and adapted according to this. A high degree of energy conservation such as the use of thermal insulation and highly efficient electrical appliances contribute to substantial energy savings with respect to the reference case. On the supply side, the increased use of CHP for district heating ensures a maximum utilization of fuel, and the use of natural gas and renewable energy further reduce the amount of emissions to the atmosphere.

The integrated nature of the BRUS model in which energy demand plays a leading role, coupled with the detailed database resulting from the work of the various working groups and contained in the model, facilitated the formulation, calculation, and evaluation of the above scenarios.

4.1.3 The EFOM Model

Structures and software

In the Energy Flow Optimization Model (EFOM), the energy supply system is described as a network in which the demand for energy services is linked to primary fuels and emissions of pollutants through a number of energy conversion and emission abatement technologies; these are quantified by a set of parameters for availability, efficiency, costs, and emission factors, as well as physical, institutional, and policy constraints. The system is optimized by linear programming.

The EFOM Model has been used for many years, mainly by the CEC; it has been implemented on different computers using different linear programming codes. For Denmark it is implemented on Risø'ss Digital VAX Computer using the LINPROG [4] linear programming code developed by the Risø Computer Section.

The collaboration with the Risø Computer Section and the CEC Directorate General for Science, Research and Development (DG XII) on the software development continued in 1990. The Risø implementation became the reference point for the VAX Version of the software which was implemented at CEEETA, Lisbon, Portugal and EOLAS, Dublin, Ireland. The LINPROG optimizer is now licensed to the Commission to be used for EFOM on various computers, e.g. the SUN workstation under UNIX.

The EFOM software, written in FORTRAN, is being revised into a portable software package to be used on mainframes, workstations, and large PCs under DOS. A series of spreadsheets is being developed to create interfaces between the EFOM Model and data from various origins (e.g. the BRUS Model) and present results in tables and graphs.

EC studies on emission abatement

In 1990 the CEC Directorate General for Science, Research and Development (DG XII) published a report on methodology for assessment of acid pollution in Europe [5] under the JOULE energy research programme. The research project was begun in 1986 and utilized about twenty research teams in all EC countries.

The Energy Flow Optimization Model with Environmental Measures (EFOM-ENV) was developed and consolidated during this project as a working tool for making cost-efficiency analyses of emission abatement, and a framework for selecting technical and economic data for multinational studies. Work under this programme continues; in 1990 the main task in 1990 was a study of »A CO_2 Constrained Policy«. A »Crash Programme« involving a few, representative countries was carried out for the preparation of the Second World Climate Conference in Geneva in November 1990, and similar studies were completed for all EC countries by the end of the year.

The technical options for CO_2 reduction were studied in three subprogrammes: DERE (Développement des Energies Renouvable en Europe), FRET (Fossil fuel Reduced Emission Technologies), and MURE (Modèlee d'Utilisation Rationelle de l'Energie). The Danish contribution to these studies was an extract of the technical and economic data from the BRUS model that was developed for the Danish energy plan, »Energy 2000«. The scenario assumptions concerning economic development, demand for energy services, and fuel import prices were based mainly on the Energy 2010 Study by the CEC Directorate General for Energy (DG XVII) [6].

Figure 4.3 shows some of the main results for Denmark. The base year is 1988; the Reference scenario assumes the existing legal constraints on emissions on SO_2 and NO_x, and no further promotion of conservation measures; the MURE scenario includes a number of cost-effective conservation measures; and in the Reduction Cases there are overall CO_2 constraints that are tightened successively. The results for Denmark fol-

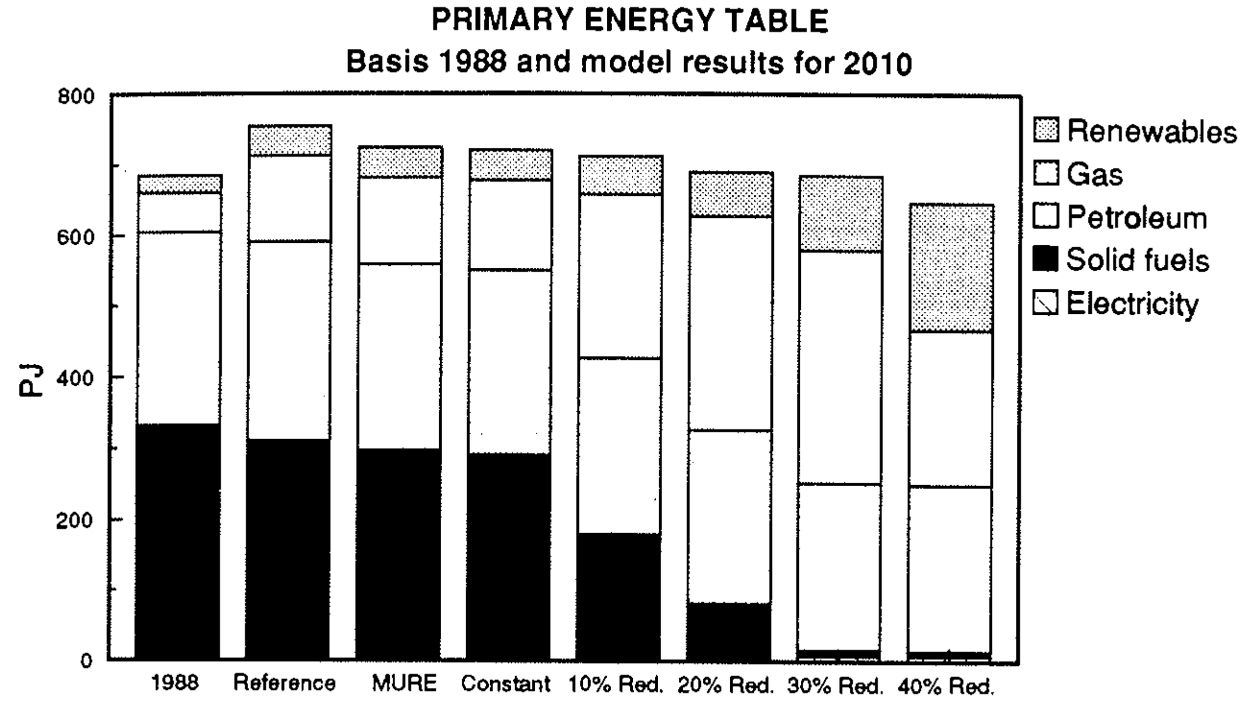
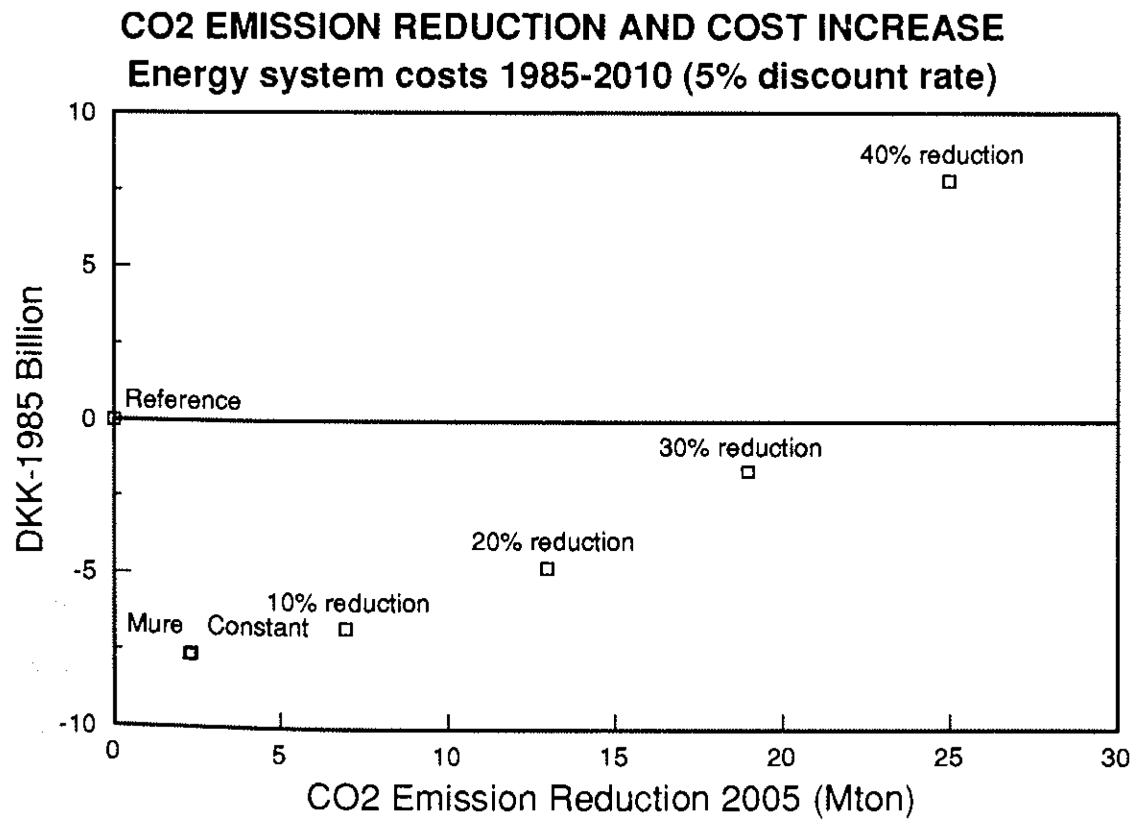


Figure 4.3. Primary energy demand (PJ)

Figure 4.4. CO_2 reduction cost curve (2005)



low the pattern which was found for the countries participating in the Crash Programme. However, when gas imports are unconstrained, the Danish potential for CO_2 reduction is large because the use of gas as a substitute for coal in power production leads to lower emissions of CO_2 per supplied kWh.

Figure 4.4 shows the CO_2 reduction by 2005 and the discounted energy system costs for the whole model period. When the model is allowed to choose savings measures, the total costs must fall. The CO_2 constrained scenarios show that even at 30% CO_2 reduction from 2005 compared to 1988, the extra costs will not outweigh the gain from the few savings options that were included in this study. The 40% Reduction case shows an extreme situation which might not be feasible as it will require large-scale introductions of immature renewable technologies.

The main elements for a CO_2-reduction policy found in the study were: energy conservation, the use of natural gas for electricity generation by new, more efficient technologies, and penetration of renewables. Tighter CO_2-reduction targets will also require reductions in natural gas use and its replacement by non-fossil fuel technologies.

4.2.4 Emission Inventories

In 1990 the group was active in several projects related to the quantification and assessment of emissions to the atmosphere, particularly from the energy system.

During the year the group worked on assessing the level of Danish greenhouse gas emissions. This will result in a report to be published early in 1991 detailing the emissions of carbon dioxide(CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFC), from both anthropogenic and natural sources. The work was carried out in collaboration with the National Environmental Research Institute. It was initiated and partly financed by the Ozone and Climate Committee of the Nordic Council of Ministers, with ESG's contribution being financed by the Danish Environmental Protection Agency.

In 1989 the National Council for Research Planning carried out an evaluation of Danish environmental research. One of the recommendations of the evaluation was that there should be better coordination of atmospheric research. To this end Risø and the National Environmental Research Institute formed the Danish Centre for Atmospheric Research (DECAR) whose aims are to arrange the exchange of information, develop new areas of research and facilitate cooperation between different institutions regarding scientific education and international contacts. During 1990 ESG played an active role in the work of the Emission Data Group of DECAR and also participated in the Climate Change Group.

During 1990 the group continued to participate in the CORINAIR emissions inventory programme of the CEC. Extensions of the CORINAIR inventory to include emissions from ships and aircraft, as well as CO_2, CH_4, N_2O and NH_3 are planned. In conjunction with this the group carried out preliminary work on incorporating emissions from ships into the CORINAIR system.

Existing estimates of the emissions of volatile organic compounds (VOC) are subject to great uncertainty due to the lack of reliable data and the experimental nature of the measurements involved. Work was started in 1990 on a project aimed at improving the estimate of voc emissions. The project is being carried out in collaboration with dk-Teknik and financed by the National Agency of Environmental Protection. It will be completed in 1991.

4.1.4. The INDUS Model

INDUS is a model that converts forecasts for national economic development from the ADAM model (the macro-economic model used by the Danish Ministry of Finance) to forecasts for industrial energy consumption for the same period. The industrial sector is divided into 22 different branches using 4 fuel types.

The work on using INDUS in 1990 took two directions: First, in relation to "Energy 2000" the INDUS model was supplemented with a sub-module that divides energy consumption into end-uses such as heating and lighting. Energy savings on specific technical appliances were also introduced into the model. The model was then used to analyse the effect on total industrial energy consumption which would result from the implementation of a range of specific technical energy savings.

Second, in the course of a general updating of the model in 1990, INDUS was enlarged to include the primary and construction sectors, so that the model now covers the complete process sector. In addition, INDUS was supplemented with a sub-model called EMIS to calculate the energy-related emissions of CO_2, SO_2, and NO_x.

As a by-product, CO_2, SO_2 and NO_x emission coefficients for the fuels specified in the energy balances of the Danish Statistical Office have been calculated.

4.1.5. Integrated Energy and Environmental Modelling

A methodological study initiated in 1990 aimes at clarifying what should constitute the contents of a common planning goal such as sustainable development. The study focuses particularly on the energy systems in the Nordic countries and the Baltic area, and is financed by Risø and the Nordic Council of Ministers.

As far as the project is concerned, sustainability is understood as a qualitative measure of how energy systems influence the ecosystem in the long term through the depletion of exhaustible resources and deterioration of environmental quality. These effects are subject to a valuation of how the energy system influences the wealth of future generations. At the same time, an economic valuation of the stock of capital wealth and productive resources, and a valuation of the quality of the total ecosystem are made. Finally, it is important to recognize the distributional effects of environmental impacts and resource depletion both nationally and internationally.

It is important to emphasize the time horizon in relation to the sustainability concept. Thus, energy planning must be considered within a long time horizon so that environmental effects and the depletion of exhaustible resources are given appropriate weight in the planning process. This is illustrated in more detail in Figure 4.5, which distinguishes between a sustainable adapted energy system in the short and long terms.

Energy and environmental planning within a short time horizon is described more specifically as follows: The energy supply system utilizes a small number of different commercially available fuel resources. Different types of fuels are used in merit order according to costs and rules in force for environmental protection and safety. A number of detrimental environmental effects are associated with the energy conversion process; these may include emissions to the air, noise, and smell. Up to the present, the energy conversion system was not required to bear all the costs associated with environmental effects as would be the case if one considered that polluters ought to be liable for damage to their "victims". The energy conversion system has nevertheless already suffered increasing production costs, such as expenses for flue gas desulphurisation systems.

Energy and environmental planning within a longer time horizon is characterized by many possibilities for change, because research and investment in technological improvements may influence the availability of fuel resources and energy conversion technologies in the future, as well as future energy demand. Furthermore, it must be expected that feedback mechanisms associated with negative environmental effects will be more complex and powerful within the long- rather than short-time horizon. One reason for this is that environmental effects of energy production within the long-time horizon include both "short-term effects" and "accumulated effects". Besides, it must be expected that new information may be brought to light on dangerous environmental effects caused by energy systems and pollutants, and these may be very costly to manage.

Planning within a long-time horizon is subject to considerable uncertainty. Even so, the long-time horizon is necessary for properly defining overall goals for technological development and achieving sustainable development at the least possible socioeconomic cost.

A specific study within the present project coupled emission scenarios for SO_2, NO_x, and CO_2 for the Nordic countries to similar scenarios for the former DDR, Poland and the European part of the Soviet Union (in the following called the Baltic countries) using the RAINS model developed by IIASA [7]. The purpose of the analysis was to investigate the environmental impacts of reduced emissions of SO_2 and NO_x in the Baltic area in order to give a first indication of the advantages of a common cost-efficient abatement strategy in the area.

An important conclusion of the study was that a sound background exists for an international agreement on abatement policy for sulphur and nitrogen emissions. Such an agreement could lead to economic advantages for the region as a whole. This is due mainly to the difference between the Nordic countries on the one hand, which have already gone a long way in emission abatement, and the former DDR, Poland and USSR on the other hand, where little has been done. This means that relatively cheap abatement measures, such as flue gas desulphurisation systems, are already used or scheduled in the Nordic

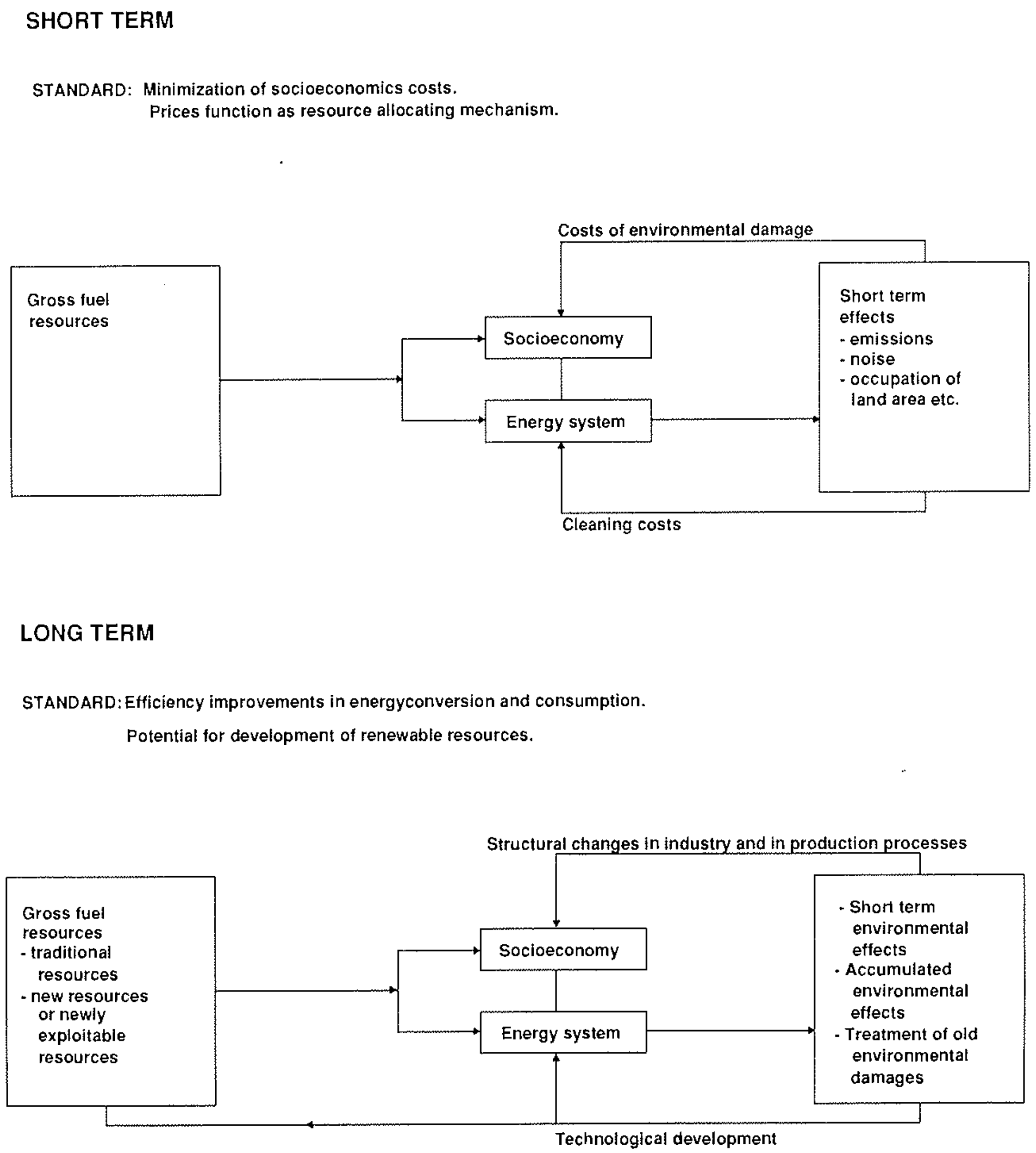


Figure 4.5. A sustainable adapted energy system in the short and long terms.

Nordic countries. Further emission reductions in these countries are expected to be relatively expensive, however.

4.1.6. Baltic Energy Collaboration

In the autumn of 1990 the group of Policy Officials, Department for Energy Market Problems under the Nordic Council of Ministers financed a project with the title "Baltic-Nordic cooperation in the field of energy and environment".

The project is being carried out by the Technical Research Centre of Finland (VTT) and Risø. One purpose of the project was to collect existing information on the energy systems in Estonia, Latvia, and Lithuania in order to set up energy balances, descriptions of the energy demand and supply situation, and the present emissions from the energy system. The other purpose was to establish contacts within a network of people who work in this field.

A report on the energy systems in the Baltic countries is now being edited. The chapters on the different countries have been written by a group of people working at key points in the energy sector in the Baltic countries. These chapters include impressions of what they consider the main problems in the present energy systems. This information and the contacts created should provide a good background for future cooperative projects between the Baltic and Scandinavian countries.

A workshop was held in Helsinki in December 1990, where all the Baltic authors presented their material, and a group of presentations on the Scandinavian energy system were given.

Table 4.1 shows figures for electricity supply and consumption in the Baltic countries in 1985, along with Danish data for comparison. It can be

Table 4.1. Electricity supply and demand in 1985

(Electricity in TWh)	Estonia	Latvia	Lithuania	Denmark
Production	16.1	4.6	20.9	25.6
Consumption	6.6	7.9	13.2	25.4
Grid-losses	1.1	1.2	1.6	2.0
Export	8.4	-4.5	6.1	-1.8
Consumption in kWh/capita	4130	3040	3570	4980

seen that the electricity consumption per capita is lowest for Latvia. This is because of the absence of heavy industry. However, we note that the figure for Denmark is no more than about 70% higher than the Latvian figure, despite the much greater difference in industrial production.

It can also be seen from Table 4.1 that electricity consumption in Latvia is twice the domestic production, and hence the country is highly dependent on power imports.

Estonia and Lithuania, on the other hand, are electricity exporters. In Estonia electricity is produced by burning shale-oil in power plants that cannot ensure up-to-date environmental standards. The technology used for oil shale mining and processing is obsolete, and environmental conditions in the north-east of Estonia are very poor.

The 2500 MW Ignalina nuclear power plant in north-eastern Lithuania consists of two Chernobyl-type reactors. The construction of a third such reactor was halted by public pressure. The continued operation of the plant gives rise to potentially serious environmental effects; however, if closing is mandatory, Lithuania like Latvia, will be without an adequate power supply.

The Baltic collaboration project will continue in 1991, concentrating on future energy strategies for the Baltic countries.

4.1.7. Wind Energy Planning in Egypt

In the beginning of 1990, the group participated in a feasibility study on utilizing of wind energy for electricity production at promising coastal areas on the Red Sea. The study also involved a review of the capacity in Egypt for manufacturing wind turbines, and the formulation of a project proposal, if this were found to be relevant. The study was commissioned by Danida and carried out in collaboration with the Test Station for Wind Turbines at Risø and consultant C.E. Wegener.

The feasibility study found the area to be very promising for wind energy, and it proposed Danish assistance for a programme to introduce wind energy. It was suggested that such a programme could consist of

(1) institutional support for planning the large-scale utilization of wind energy,
(2) establishing a national wind energy technology centre, and
(3) financial support to procure locally manufactured wind turbines.

As a result of the findings of this study and on the basis of an earlier UNDP project concerning the manufacture of wind turbines, a project was formulated for demonstration and development of technology, and planning in the wind energy sector in Egypt. An immediate action programme was put into operation in 1990.

The immediate action programme involves several different units at Risø. ESG is responsible for the planning component. This consists of support for the preparation of a master plan and enhancement of the capabilities of the wind energy section of the New & Renewable Energy Authority (NREA) in Egypt. The aim is for NREA to be fully able to plan and coordinate the successful large-scale introduction of wind energy.

Within the immediate action programme, two three-week working sessions took place in 1990, the first in Cairo during October and November and the second at Risø during November and December. The outcome of these working sessions has been proposals for organizing and developing a framework for the master plan. Furthermore, potential useful planning models and planning methods were studied and discussed.

4.1.8. Energy Planning for the Cape Verde Islands

In late 1990 work was started on a project of technical assistance to the Ministry of Industry and Energy, Cape Verde. The project is commissioned by Danida.

One member of the group was seconded to the Ministry in Cape Verde to prepare an energy plan.

The components of the energy plan include a description of the present state of the energy system, a number of forecasts (population, energy consumption, energy prices, etc.), and the consequences of different strategies (fuel demand, investments, labour requirements, foreign currency demand, etc.).

In order to provide the Cape Verde islands with a cheap and stable supply of energy, a wide variety of possibilities must be considered. The balance of trade does not allow an increase in the energy import; however, conservation of energy, fuel substitution and security of energy deliveries require special attention, and must be treated in extensive detail.

4.1.9. Electricity Production Versus Electricity Savings

Until now, the extension of electricity production plants has been dependent on demand. Nevertheless, in recent years it has been the policy to invest in electricity savings measures instead of extending electricity capacity as a less costly alternative. In 1990 a project dealing with this question was initiated.

In the project a model concerning electricity savings measures is being developed. The model considers the correlation between savings and future electricity supply. Thereby it will be possible to investigate how much one may invest in savings instead of in adding to the present supply.

The aim of this project, financed by the Nordic Council of Ministers is to demonstrate the model for each of the Nordic countries, as the electricity supply varies considerably from one country to another. At first, the model will be demonstrated for Denmark in order to test the methodology, before extending the model to the other Nordic countries.

By the end of 1990, data concerning the electricity forecasts in Denmark in the year of 2010 and the extension plans for the electricity system had been obtained and the model was then developed. A report concerning the first half of the project is to published January 1991.

4.1.10. Integrated Models and Uncertainty

A Ph.D. project to study integrated models and the associated uncertainties has been initiated. The aim of the work is to discover how uncertainties of various kinds can be identified, characterized, represented and integrated in the planning and decision-making process.

A search for relevant articles and books in the accessible literature was carried out. Literature on a variety of energy and environmental models, national and international, was studied. Special attention was paid to the RAINS model for Europe [7] for which a variety of uncertainty and sensitivity analyses has been made. In that connection, IIASA was contacted to look into prospects and arrange details of work with the RAINS model. The work, which will include a general uncertainty analysis of the integrated model, will start in February 1991 and will be completed during a 6-month stay at IIASA.

Based on the knowledge obtained in the introductory literature study, a theory concerning uncertainty analysis has been closely examined. "Uncertainty" includes analysis of problem formulation, analysis of inventory uncertainty, screening and ranking of uncertainty, evaluation of uncertainty, and application to decision-making. Each of these studies includes a number of technical and mathematical methods.

Integrated models are often used to obtain an overview in connection with research management, policy analysis, and regulatory decision-making. A study of planning and decision-making processes therefore forms part of the project. A course in public planning was followed at the Technical University of Denmark, and in conjunction with the course, an analysis of the Danish Water Action Plan was carried out in a case study describing critical assessments of the plan and the decision-making process.

The work with the RAINS model and Water Action Plan will continue and these case studies will be used to outline general theoretical aspects of the treatment of uncertainty.

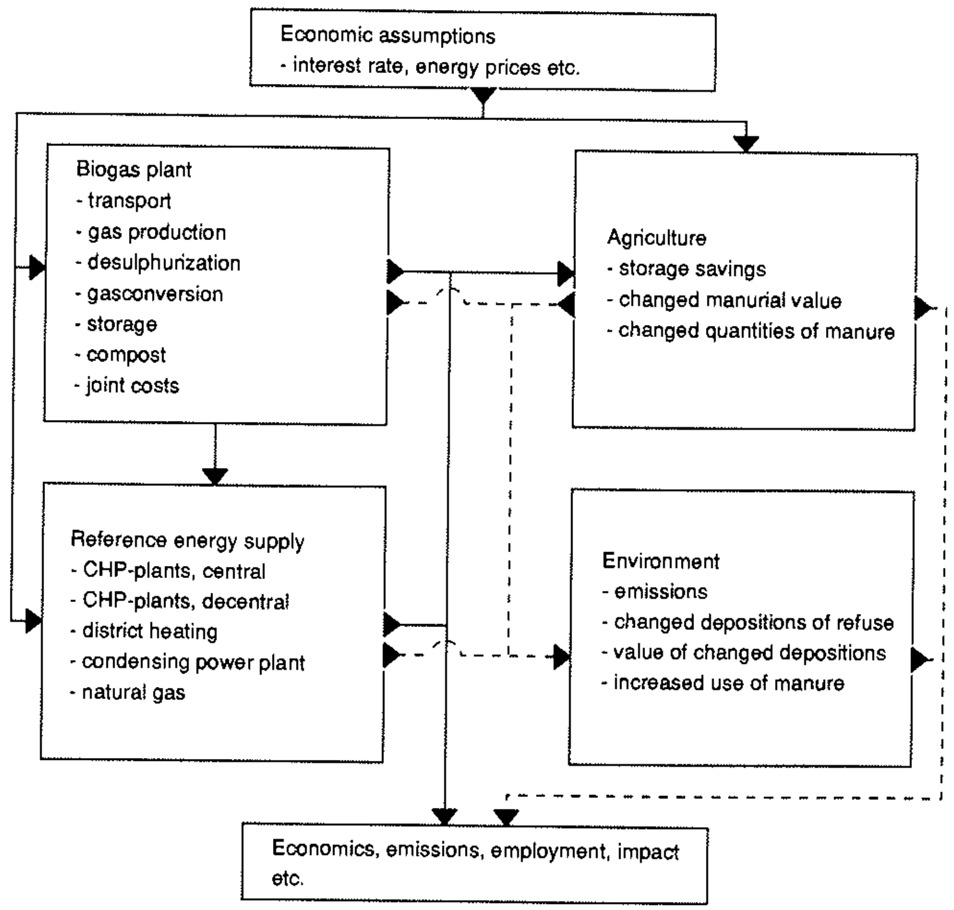
4.2. Energy and Environmental Technologies

4.2.1. Assessment of Joint Biogas Plants

In 1986 the Danish Ministry of Energy set up the Coordinating Committee for Joint Biogas Plants. The main objective of this committee was to prepare and coordinate a Plan of Action for such plants and the plan was formulated during the period 1988-90.

In accordance with the plan, the Energy Systems Group in collaboration with the Institute of Agricultural Economics studied the social economic consequences of establishing joint biogas plants from the energy, environmental, and agricultural points of view. To facilitate these calculations, a model was developed and its structure is shown in Fig. 4.6.

Figure 4.6. Structure of the model for biogas plants



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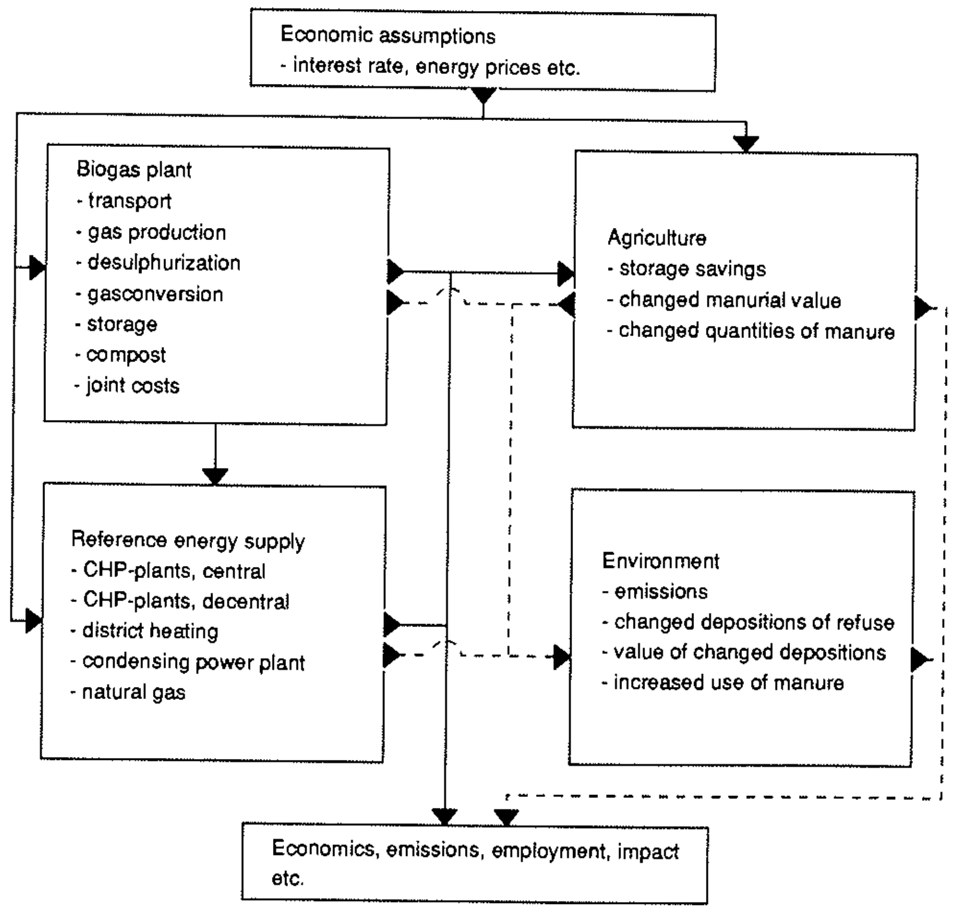

The biogas plant is split into 7 modules representing different technology components (transport, gas production, etc.). Each of these components is characterized by various economic and technological data (investments, operation and maintenance costs, efficiency, etc.).

The economic consequences of establishing biogas plants are calculated with respect to the alternative energy production possibilities. For that reason a number of feasible reference supplies are incorporated in the model for comparison. As can be seen from Fig. 4.6, these range from centralized combined heat and power plants to small-scale incineration plants with heat and power cogeneration. It is also possible to compare the production costs of biogas, only (before conversion to electricity and/or heat) with the use of natural gas.

The agricultural and environmental aspects are treated in three separate modules:

a) savings for farmers with regard to storage of manure when the biogas plant is established.
b) change in the volume of manure due to the inclusion of industrial refuse, and change in the manurial value due to the treatment in the biogas plant.
c) reduced costs for waste deposal due to the use of industrial refuse (e.g. offal) as manure after treatment by the biogas plant.

The main results of the calculations are: net present value, levelized costs, including capital, fuel and operation, and maintenance costs, emissions of CO_2, SO_2, NO_x, methane and ammonia.

The preliminary results show that:

- the use of biogas plants is substantially more expensive per delivered kW than conventional energy plants.
- savings introduced by agricultural and environmental aspects have a substantial impact upon the results, though biogas plants will still be more expensive than traditional plants, but they may be more competitive when lowered environmental damage from their lower emissions are taken into account.
- establishing biogas plants will reduce emissions substantially, especially of carbon dioxide (CO_2).

4.2.2. A System for Wind Energy Planning

During 1990 a Wind Energy Planning (WEP) system has been developed. The system is intended for decision support in the economic evaluation of wind energy projects, ranging from single wind turbine installations to large windfarm projects consisting of many wind turbine plants.

In the WEP system, a wind turbine is described by data on initial investment, possible later reinvestment, operation and maintenance costs, expected annual production, lifetime, and capacity factor. The alternative conventional power production is modelled by its specific investment, operation and maintenance costs, lifetime, effectivity, fuel mix, and time series for fuel prices (coal, fuel oil, diesel oil, and gas). Using these data, capacity credit and saved fuel and O&M costs are calculated. The calculation also includes the raising of loans.

The data structure of the model is very flexible. This allows the user to create a scenario that models a large-scale introduction of wind power from data on single wind turbines or single windpower plants. In such a scenario the gradual build-up of wind power capacity over several years can be modelled.

The system is based on menues in which the user chooses between various facilities by a single keystroke, e.g. the input facility for giving data, or the report facility for calculating output reports. The WEP system is based on the Framework software system run under DOS on an IBM-compatible PC.

4.2.3. Sewage Treatment Plant

During winter the nitrification process in sewage treatment plants (STP) is often ineffective due to low temperature, and at temperatures below 6oC the nitrification process stops completely.

In 1988 a project was initiated in collaboration with I. Krüger A/S and financed under the Danish Energy Research Programme 1988 (EFP88). The aim of the project is to analyse the energy-related aspects in STP with a view to increasing plant performance during winter. One possible solution might be to cover the plants in order to reduce heat losses.

Temperatures were measured in different plants during the winters of 1988/89 and 1989/90, but unfortunately the temperatures did not drop below 6°C. During the winter of 1989/90 datalogging was made on 2 plants, and the data have been used for demonstrating a model concerning temperature drops. The model calculates net heat loss by convection, radiation, and evaporation. In this way it may be possible to estimate which factors such as, wind velocity, relative humidity or precipitation contribute most to the temperature drop.

The project will continue into 1991 in the hope of collecting data during a cold winter in order to demonstrate the model, and at the same time identify a possible solution to the energy-related problems in STP. A report concerning the project up to 1990, including documentation of the model, will be published in the near future.

5. UNEP Collaborating Centre on Energy and Environment

The UNEP Collaborating Centre on Energy and Environment was established on 1 October 1990 as a new unit in the Systems Analysis Department. The Centre is funded jointly by the United Nations Environment Programme (UNEP), the Danish International Development Agency (Danida) and Risø, provisionally for a four year period.

The main objective of the Centre is to promote and facilitate the incorporation of environmental aspects into energy planning and policy both at national level in developing countries and in UN agencies and other international organizations. The activities of the Centre are governed by a Management and Policy Committee with representatives from the three sponsoring organizations along with an observer from the Danish Environmental Research Institute (DMU).

The work programme of the Centre is concentrated on the following four areas:

Assessment of environmental impacts from energy production and use. The first priority is data collection and studies of greenhouse gas emissions with the aim of establishing a data and information inventory on global emissions. The efforts of the Centre focus particularly on improving the data on contributions from developing countries. This is supported by collecting information on efficient energy production and end-use technologies, potentials for energy conservation, and the environmental impacts of specific energy technologies. Such information will be used to propose means for promoting emission reduction strategies.

Energy policy studies in selected countries and the formulation of guidelines for incorporating environmental considerations into energy policy. The policy studies will be carried out by teams in the respective countries, with support from the Centre. In the first instance priority is given to the major developing countries. The aim is to determine the environmental consequences of current energy plans and policies, and to suggest alternative strategies for reducing the environmental impact while maintaining the same energy services.

Information centre on energy-related environmental effects, energy planning methods and models. Establishment and maintenance of databases and dissemination of information to UNEP, other UN agencies, governments and other interested institutions and individuals, through reports, books, newsletters, etc.

Scientific and technical support to UNEP on energy questions on an *ad hoc* basis. This includes participating in conferences and expert groups, preparing background papers, gathering information on specific topics, etc.

In the three months since the Centre was established, activities were directed mainly towards making the Centre operational. This involved recruiting staff, establishing the offices and equipment, preparation of information material, etc. It is expected that by the spring of 1991 an international, multi-disciplinary team consisting of four full-time professionals and a secretary will be in place. The Centre will be also able to host guest researchers from collaborating institutions in developing countries for short or extended periods.

Within the four activity areas work has focused on preparing a major energy-environment policy project to be implemented in India with UNEP funding. The project, which is expected to start by mid-1991, will be executed by the Tata Energy Research Institute (TERI) in New Delhi in collaboration with the relevant government ministries over a three year period. The role of the Centre will be to support and collaborate with TERI, particularly on the environmental impact and policy strategy aspects.

The Centre has already provided support to UNEP Headquarters both through *ad hoc* assistance and direct secondment of one staff member to UNEP for 6 weeks. Centre staff have been designated as UNEP representatives at international meetings, for example in connection with the work of the United Nations Solar Energy Group on Environment and Development.

6. Publications, Lectures etc.

6.1. Publications

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6.2. Lectures

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Andersen, V. et al. IT support for Emergency Management – ISEM. ESPRIT exhibition, Brussels, Belgium, Nov. 1990.
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Grohnheit, P.E. Economic Interpretation of the EFOM Model. International Symposium on Economic Modelling, University of Urbino, Italy, 23rd-25th July 1990.
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Grønberg, C.D. Risk-information, observations on risk analysis and risk debate in Denmark (paper in Danish). Nordic Seminar on Radioactive Waste, NKA/SKB, Hässelby Slott, Stockholm, Sweden, March 14, 1990.
Grønberg, C.D. Expert systems and emergency management (paper in Danish). Conference on transport of dangerous goods. Karlsted, Sweden, March 21, 1990.
Grønberg, C.D. Risk analysis a cross scientific illusion? Annual Meeting of the Society for Technology analysis and evaluation. Gilleleje, November 29, 1990.
Grønberg, C.D. Risk analysis, Risk evaluation and Risk management. Guest lectures on the Chemistry Institute, University of Odense. December 13, 1990.
Halsnæs, K. "Integrerede energi- og miljømodeller" (Integrated energy and environmental modelling) Roskilde University Centre, 19 January 1990.
Halsnæs, K. Sustainability as a planning criterion in integrated energy and environmental modelling. Nordic Workshop on integrated energy and environmental planning, Risø 15-16 February 1990.
Halsnæs, K. and Morthorst, P.E. Long-term energy scenarios for Denmark. The need for a sustainable development, Conference on environmental economics, Venice 17-20 April 1990.
Halsnæs, K. Aspekter ved en fælles energi- og miljøstrategi for norden og det baltiske område. (Aspects of a common energy and environment strategy for the Nordic countries and the Baltic area). Ålborg University Centre, 27 September 1990.

Halsnæs, K. Problemer forbundet med energisystemets tilpasning til en målsætning om bæredygtig udvikling (Problems associated with the adjustment of the energy system to the goal of sustainable development) Research seminar on energy and society, (Risø, AKF, RUC) Risø 19 September 1990.
Halsnæs, K. Samfundsm£ssig prioritering af indsatsen med luftforurening (Social priorities of investment to combat air pollution). Koncensuskonference om prioritering af luftmiljøindsatsen. Dansk Ingeniørforening og Teknologinævnet, 22-24 October 1990.
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Halsnæs, K. Implementation of energy conservation strategies. Workshop on Nordic-Baltic cooperation on energy and environment. Technical Research Centre of Finland, Helsinki 10-12 December 1990.
Hansen, J.P. Simulation of cognitive behaviour in computer games on cognitive modelling. 2nd MOHAWC workshop, Manchester, UK, 27-28 Nov. 1990.
Hansen, J.P. øjenbevægelsesregistreringer anvendt til designtestning (Eye-movement registration applied to design testing). Datateknisk Forum ERFA-gruppe 11: "Menneske-maskin samspil", Risø, 8 March 1990.
Hansen, J.P. Udvikling af asynkrone synsfikseringsmønstre som indikator på dannelsen af en dynamisk domænemodel ved indlæringen af motoriske færdigheder (Development of asynchronous eye fixation patterns as an indicator of a dynamic domain model in learning of motor skills). Framework Project on Representation and Processing of Knowledge, 1st workshop, Gentofte, Denmark, 26-27 April 1990.
Hansen, J.P. Ecological man-machine interface design. Kemira International Automation Development Seminar, Fredericia, Denmark, 31 May 1990.
Hansen, J.P. Means, scenes and methods for ecological interface design. First European Workshop on Ecological Psychology, Marseilles, France, 7-8 June 1990.
Ketscher, L. How to support decision making by computer simulation. Nordic Railway Seminar on Man and Security, Copenhagen, Denmark, 2 March 1990.
Kilde, N.A. CORINAIR and Sea-based emissions from ships. EMEP workshop on emissions from ships, Oslo, 7-8 June 1990.
Løvborg, L. Use of computer games for modelling cognitive skills. Framework Project on Representation and Processing of Knowledge, 1st workshop, Gentofte, Denmark, 26-27 April 1990.
Løvborg, L. (with Brehmer, B.) NEWFIRE A flexible system for running simulated fire-fighting experiments. 2nd MOHAWC workshop, Manchester, UK, 27-28. Nov. 1990.
Morthorst, P.E. Long-term scenarios for the Danish energy system, Nordic workshop on integrated energy and environmental modelling, Ris§, 15-16 Feb. 1990.
Morthorst, P.E. Dansk energipolitik og Brundtland-handlingsplanen (Danish energy policy and the Brundtland action plan). Seminar for industrial managers, Risø 22 March 1990.
Morthorst, P.E. The Danish Brundtland Energy Plan. Workshop at the International Atomic Energy Agency, Vienna, 2-6 April 1990.
Morthorst, P.E. Brundtland scenariemodellen og energihandlingsplanen (The Brundtland scenario model and energy action plan) Seminar for the Danish Utilities Research Institute, Risø.
Morthorst, P.E. The Danish Brundtland Energy Plan, Seminar for Greenpeace International, Risø 29 May 1990.
Morthorst, P.E. Energihandlingsplanen (The energy action plan) Roskilde Rotary, 3 September 1990.
Morthorst, P.E. Danish Energy Planning. Seminar on wind energy and energy planning, Cairo, Egypt, 14 October 1990.
Morthorst, P.E. Danish Energy Policy. European seminar on government energy policies, Vienna 26-27 November 1990.
Morthorst, P.E. and Bach, P. Energiprisernes betydning for energihandlingsplanen (The role of prices in the energy action plan). Dansk Energiøkonomisk Selskab, 3 December 1990.

Nielsen, L.H. Miljøbelastninger ved energiproduktion til bygningsopvarmning (Environmental impact of energy production for space heating of buildings). NBS-konference: "Bygningers totalenergiforbrug og miljøbelastning", Copenhagen, 11 September 1990.
Ott, S., Smith-Hansen, L. Udslip og spredning af gasser (Release and Dispersion of Gases) University of Lund, Sweden, 27-28 November 1990.
Paulsen, J. L. "Et nordisk forskningsprogram, driftssikkerhed og vedligehold". (A Nordic research programme, operational safety and maintenance). Elkraft 15, May 1990.
Pejtersen, A.M. The BOOKHOUSE. Annual Library Meeting on the Ambitious Library, Bergen, Norway, 15-16 March 1990.
Pejtersen, A.M. The BOOKHOUSE. Seminar for computer consultants and designers of library systems. Kommunedata, Aalborg, 6 June 1990.
Pejtersen, A.M. Icons for organization and representation of domain knowledge in interfaces. First Internat. Conf. on Knowledge Organisation, Darmstadt, Germany, 14-17 Aug. 1990.
Pejtersen, A.M. The BOOKHOUSE. International IFLA Meeting on Automatisation of Libraries, Copenhagen, 20-23 Nov. 1990.
Pejtersen, A.M. Design of information retrieval systems based on cognitive work analysis. Internat. workshop on Intelligent Acces to Information Systems, Gesellschaft für Mathematik und Datenverarbeitung and University of Colerado, Darmstadt, Germany, 1-2 Nov. 1990.
Pejtersen, A.M. Taxonomy of complex work domains and design of ecological interfaces. German-Danish meeting for mutual exchange and cooperation in information science arranged by Gesellschaft für Mathematik und Datenverarbeitung, Royal School of Librarianship, Denmark, and Danish Ministry of Education, Cologne, Germany, 15-16 Nov. 1990.
Pejtersen, A.M. The BOOKHOUSE. Seminar on Cognitive Work Analysis, Technical University of Denmark, Lyngby, 6 Dec. 1990.
Petersen, K.E. Risikoanalyse anvendt ved vurdering af et kontrol/alarmsystems udformning. (Risk Analysis used in assessment of the configuration of a control/alarm system). Seminar on treatment of alarms, fault diagnostics and fault treatment, Danish Society for Automation, Copenhagen, 5 December 1990.
Petersen, K.E. "Pålidelighedsanalyse" (Reliability Analysis). Risø seminar for Danish Society for Quality Control. 28 March 1990.
Petersen, K.E. "Pålidelighed og vedligehold" (Reliability and Maintainability). Risø Seminar for Danish Society for Process Automation. 25 September 1990.
Rasmussen, B. "Uønskede kemiske reaktioner" (Unwanted chemical reactions). The Technical University of Denmark. 20 March 1990.
Rasmussen, B. "Risikoanalyse af trykimprægneringsanlæg" (Risk analysis of vacuum pressure impregnation). Dansk Ingeni§rforening. Society for Risk Assessment. 31 January 1990.
Rasmussen, B., Smith-Hansen, L. "Risikoanalyse af kemiske anlæg" (Risk Analysis of Chemical Plants) 25 January 1990, Roskilde University Center.
Rasmussen, J. Use of field studies for design of work stations for integrated manufacturing systems. Address delivered at Internat. Conf. on Human Factors in Design for Manufacturability and Process Planning, International Ergonomics Association, Honolulu, Hawaii, 12-16 Aug. 1990.
Rasmussen, J. Cross-disciplinary research issues in high hazard low risk operations. Invited keynote lecture at First World Congress on Safety Science, Cologne, Germany, Sept. 1990.
Schmidt, K. Cooperative decision making. Framework Project on Representation and Processing of Knowledge, 1st workshop, Gentofte, Denmark, 26-27 April 1990.
Schmidt, K. Datamatstøttet sagsbehandling (Computer-aided case treatment). Danske Jurister og Økonomers Forbund, Copenhagen, 3 May 1990.
Schmidt, K. Analyzing cooperative work in advanced manufacturing. 2nd International Conference on Human Aspects of Advanced Manufacturing and Hybrid Automation, Honolulu, Hawaii, 12-16 Aug. 1990.
Schmidt, K. The Procrustes Paradigm: A critical appraisal of work analysis methodologies. Co-Tech WG4, Brussels, Belgium, 6 Sept. 1990.
Schmidt, K. A critical appraisal of work analysis methodologies. Seminar on Cognitive Work Analysis, Technical University of Denmark, 6 Dec. 1990.
Thomsen, Niels Juhl. "Economics of Hurghada demonstration wind farm methods and considerations". Seminar on wind energy. Cairo October 1990.
Thomsen, Niels Juhl. "Danish energy planning, Energy 2000". DA seminar for upper managers from the energy sector in Czechoslovakia, Æbeltoft, November 1990.

Thomsen, Niels Juhl. "The new Danish energy plan, possibilities for energy conservation in the industrial sector". Workshop on Baltic Nordic cooperation on energy and environment. Technical Research Centre of Finland, Helsinki, 10-12 December 1990.

6.3. Participation in Committees

Danish:

1. Research committee for industrial processes and products (Min. of Energy).
2. Steering group, scenarios for energy consumption in transport.
3. Electricity forecasting group (Min. of Energy).
4. Steering group, Staff Training and Institutional Strengthening (Danish Energy Agency).
5. Inter-ministerial committee on energy policy in the EC (Min. of Energy).
6. Risk assessment committee (Academy of Technical Sciences).
7. Steering committee, Danish Society for Risk Assessment.
8. Environmental Appeal Board.
9. V.E. data.
10. DIF's udvalg vedr. norm for risikoanalyse (Committee on standards for risk analysis).
11. Working group on energy use in buildings (Min. of Energy)

International:

1. Ad hoc expert group of the CAN-JOULE for energy and environmental models. (Commission of the European Communities).
2. CGC5 Nuclear fission energy, safety (C.E.C.).
3. Steering committee, European Safety and Reliability Association.
4. Editorial board, Journal of Loss Prevention in the Process Industries.
5. Editional board, Nuclear Instruments and Methods, Section A.
6. Committee for European Standards on Nuclear Electronics.
7. International Programme Committee for the Conference "$\lambda\mu$-7 on Reliability and Maintainability" June 1990, France.
8. International Organizing Committee for the Conference "REL-91; Reliability 91", June 1991, UK.
9. Steering Group. SHARE (Safety Management and Hazard Assessment Research Cooperation in Europe) (CEC, DGXII).
10. United Nations Solar Energy Group.
11. Programme Committee for 3rd International Conference on a Systems Analysis Approach to: Environment, Energy, and Natural Resource Management in the Baltic Region, Copenhagen, May, 1991.
12. Management and Policy Committee for UNEP Collaborating Centre on Energy and Environment.
13. Board of Management, Energy Centre Denmark.
14. Halden Programme Group, OECD.
15. Review Board for ESPRIT project: IT Support for Energy Management, ISEM (CEC).
16. Programme Committee for the international Conference on "Global Collaboration on a Sustainable Energy Development". Helsingør, Denmark, 25-28 April 1991.

7. Staff

Hans Larsen, M.Sc. (Elec. Eng.), Ph.D. in reactor physics. From 1973 to 1976 at Dragon project at AEE Winfrith, U.K. Risø from 1976. Energy Technology Department 1976-80, working with systems reliability. Head of Energy Systems Group 1980-84. Head of Systems Analysis Department from 1985.

Leif Hansson, M.Sc. (Elec. Eng.). Risø from 1961. Head of Computer Group/Computer Installation 1963-86, Deputy head of Department of Information Technology 1986-90. Systems Analysis Department from March 1990. Main activities: Quality Assurance in Esprit project ISEM, education of users in connection with Risø's new administrative edp system.

Risk Analysis Group

Kurt Erling Petersen, M.Sc., Ph.D. Risø from 1977. Department of Energy Technology 1977-84. Risk Analysis Group from 1984. Main activities: Development of computer codes for reliability analysis, development of tools for operation and maintenance, and treatment of reliability data. Head of Risk Analysis Group from 1990.

Palle Christensen, M.Sc. (Elec. Eng.). Risø from 1962. Electronics Department 1962-86 working on nuclear instrumentation, research instrumentation and reliability projects. Department of Information Technology 1986-88 working on knowledge-based computing. Secretary of Risø's patent council 1973-88. Risk Analysis Group from 1988. Main activity: Development of computer codes for reliability and safety analysis.

Carsten D. Grønberg, M.Sc. (Elec. Eng.). Risø from 1967. Electronics Department 1967-78. Safety Department 1978-83. Risk Analysis Group from 1984. Main activities: Human factors, emergency planning, risk management.

Jens Ole Knudsen, M.Sc. (Chem. Eng.). Risø from 1987 until September 1990. Main activities: Dynamic computer-simulation and physical modelling of release, fire, explosion and dispersion of substances from chemical process plant.

Hans E. Kongsø, M.Sc. (Mech. Eng.). Risø from 1957. Research reactor DR 2 1957-63, Department of Energy Technology 1963-84. Risk Analysis Group from 1984. Main activities: Computer codes for reliability and consequence assessment, and risk assessment of nuclear and industrial plants.

Kurt Lauridsen, MSc (Electrical engineering), PhD (Nuclear engineering). Risø since 1974. Department of Energy Technology 1974-87, working with nuclear safety and industrial risk analysis. Department of Informatics 1987-90. Risk Analysis Group from March 1990. Main activities: Reliability analysis, risk management.

Jens Peter Madsen, B.Sc. (Chem. Eng.). Risø from 1988 until May 1990. Main activities: Computer-simulation and physical modelling of release, fire and dispersion of substances from chemical process plant.

Dan S. Nielsen, M.Sc. (Elec.Eng.). Risø from 1962. Electronics Department 1962-64. Risk Analysis Group from 1984. Main activities: Risk analysis of individual plants, physical modelling for consequence assessments.

Søren Ott, M.Sc. (Phys., Math.). Risø from 1985. Main activities: Models and computer codes for consequence assessment; real time simulation of blow-downs, plume formation, and gas explosions. Ph.D. student from 1987, subject: Micrometeorological aspects of risk assessment.

Jette Lundtang Paulsen, M.Sc. Mechanical engineering, DTH 1972. From 1972-80: Research reactor DR3. From 1980-86: Uranium Extraction project. From 1986-90: Department of Informatics. From 1990 Department of Systems Analysis. Main activities: Maintenance planning, software development, interface systems.

Birgitte Rasmussen, M.Sc. (Chem. Eng.), Ph.D. The Technical University of Denmark from 1981-84. Risø from 1984. Main activities: Risk assessment of chemical plants, assessment of toxic and ecological effects from releases, and risk management.

Lene Smith-Hansen, M.Sc. (Chemistry). Risø from 1986. Main activities: Risk assessment of chemical plants, toxic effects from releases, and quantitative assessment of toxic chemical substances from combustion.

Cognitive Systems Group

Leif Løvborg, M.Sc. (Elec.Eng.). Risø from 1962. Radioisotope techniques (1962-66), nuclear geophysics and mineral exploration (1967-86). Group Leader (Electronics Dept.) 1965-86, Lead Scientist in OECD/IAEA action to improve uranium exploration methods 1979-85. Cognitive engineering research from 1986. Acting Leader of Cognitive Systems Group from Feb. 1990. Main research activity: Modelling complex, adaptive systems.

Henning Boje Andersen, M.A. (Philos.). Copenhagen University and Oxford University (logic, philosophy of language) 1976-79. Medical Faculty, Copenhagen University and Roskilde University, (philosophy of science) 1980-83. Risø from 1984, Cognitive Systems Group from Feb. 1990. Main activities: Human-computer interaction, information systems requirements, cognitive models.

Verner Andersen, M.Sc. (Elec.Eng.), Ph.D. Risø from 1966. Nuclear physics (1966-76), plasma physics (1976-86). Leader of programme on plasma-physics technology 1983-86. Information technology from 1986. Coordinator of the joint Nordic programme for nuclear emergency management (1986-90). Manager of CEC Esprit Action 2322, 'IT Support for Emergency Management' (ISEM). Cognitive Systems Group from Feb. 1990 (as Project Leader). Main activity: Project management, systems development.

Gunnar Hovde, M.Sc. (Psychol.). Lecturer in perception psychology and social psychology at Aarhus University 1975-85. Risø from 1985. Man-machine interaction, field studies within manufacture and health care. Cognitive Systems Group from Feb. 1990. Main activities: Knowledge extraction, information analysis, work analysis, accident analysis.

Finn R. Nielsen, M.Sc. (Appl. Math. & Phys.). Technical College of Copenhagen 1968-74. Risø from 1974. Computer programming for models and graphical interfaces within man-machine studies and operator support facilities, for compilers and data bases in minicomputer environments, for simulation of power plants for diagnosis and control (1974-1989). Cognitive Systems Group from Feb. 1990. Main activities: Cognitive simulation, implementation of design concepts.

Annelise Mark Pejtersen, M.A. (Sci. of Lit.). University of Copenhagen 1971-73, Associate Professor at the Royal School of Librarianship 1971-82, Acting Professor 1983-85. Visiting Senior Research Scientist at Georgia Institute of Technology 1982-83. Risø from 1986 (as Project Leader). On leave as manager of the Labour Unions' Centre for Informatics 1989-90. Cognitive Systems Group from Feb. 1990. Main activities: Project management, user modelling, ecological design concepts, multimedia interfaces, taxonomy of work domains.

Kjeld Schmidt, M.Sc. (Sociol.). Roskilde University 1972-85, Dansk Datamatik Center 1985-88, Labour Unions' Centre for Informatics 1989-90. Cognitive Systems Group from March 1990 (as Senior Scientist). Main activities: Theory and methodology for analysis of cooperative work in complex settings, Computer-Supported Cooperative Work, taxonomy of work domains.

Steen Weber, M.Sc. (Elec.Eng.), Ph.D. Risø from 1972. Computer codes for nuclear fuel management (1974-75). Risk Analysis Group (Dept. of Energy Technology) 1975-84, Acting Group Leader 1982-83. Core simulator project, risk analysis of off-shore platforms. Development and use of codes for fuel management in collaboration with Danish utilities (1984-87). Leader of project on knowledge-based system for control of heat distribution (1988-89). Cognitive Systems Group from Feb. 1990. Main activity: Advanced interfaces and data bases for information retrieval systems.

Scientific Coordinator

Jens Rasmussen, Research Council Professor, M.Sc. (Elec.Eng.). Risø from 1956. Control engineering (1956-62), Head of Electronics Dept. 1962-86. Member of Danish Academy of Technical Sciences (1962). Visiting Professor at Center for Man-Machine Systems Research, Department of Industrial Engineering, Georgia Institute of Technology, 1982-83. From 1986 Research

Council Professor affiliated to Risø and the Technical University of Denmark. Coordinator of CEC ESPRIT-2 basic research action 3105, 'Models of Human Actions in Work Context' (MOHAWC). Coordinator of the research activities in the Cognitive Systems Group from Feb. 1990.

Energy Systems Group

Niels Juhl Thomsen, M.Econ. Danish Ministry of Education 1978-79, Danish Ministry of Housing and Building 1979-81, Danish Ministry of Energy 1981-89. Joined Risø as Head of Energy Systems Group in May 1989. Main activities: General energy planning and economics of renewable energy.

Frits Møller Andersen, M.Econ. Specialized in econometrics and macro-economic modelling. Research assistant Århus University 1978. Assistant planner in local government 1979. Risø from 1980. Main activities: The macro-sectoral model HERMES for Denmark and a technical-economic model for the Danish industrial energy consumption.

Helle Christiansen, M.Sc. (Pharm.). Risø from 1986 until July 1990. Department of Energy Technology 1986-88. Joined Systems Analysis Department February 1988. Main activities: Environmental impact models.

Peter Skjerk Christensen, M.Sc. (Elec. Eng.). Risø from 1958. Nuclear research and education (1958-69), reactor engineering and thermohydraulics including simulation models (1969-76), Energy Systems Group from 1977. Main activities: Energy systems modelling. From November 1990 stationed in Cape Verde Islands as energy advisor to the government.

Jørgen Fenhann, M.Sc. (Physics with mathematics and chemistry). Niels Bohr Institute 1977. Risø from 1978. Main activities: Development of energy planning models, economics of new and renewable energy technologies, calculation of emission from energy system, and energy-environmental planning for Eastern European countries.

Poul Erik Grohnheit, M.Econ. Danish Building Research Institute 1969-71, town planning consultant 1971-72 and 1979-80, budgetting and economic planning in local government 1973-79. Risø from 1980. Main activities: Energy system and environmental modelling, and economics of power plants.

Kirsten Halsnæs, M.Econ. Danish Ministry of Housing and Building 1983-87. Risø from April 1987. Main activities: Nordic collaboration on integrated energy environmental planning, integrated models, environmental economics, energy and environment in Eastern European countries.

Lotte Schleisner Ibsen, M.Sc. (Mech. Eng.). Risø from 1984 in Research Section of the Engineering Department working on aquifer thermal energy storage. Joined Energy Systems Group in 1989. Main activity: Assessment of energy technologies.

Klaus Haahr Jørgensen, M.Sc. (Chemistry). MLKE-Næstved 1986-87. Risø from 1987. Department of Energy Technology 1987-88. Joined Systems Analysis Department February 1988. Main activities: Environmental impact models and emission inventories.

Niels A. Kilde, M.Sc. (Chem. Eng.). The Danish Steelworks Ltd. 1962-81. Research and quality control (1962), planning and administration (1967), casting department manager (1972), development and energy manager (1977). Risø from 1981. Member of the steering group for R&D in industrial processes of the Ministry of Energy. Main activities: Energy use in industry and transport, emissions inventory.

Helge V. Larsen, M.Sc. (Elec. Eng.), Ph.D. Technical University of Denmark 1974. Storno A/S from 1975. Risø from 1976. Department of Reactor Technology 1976-77. Energy Systems Group from 1977. Main activities: CHP production, modelling of energy systems, economic models for the oil and gas sector, development of planning models for wind energy.

Poul Erik Morthorst, M.Econ. Economist specialized in econometrics and macro-economics. Risø from 1978. Head of Energy Systems Group 1985-89. Main activities: General energy planning and modelling with emphasis on forecasting electricity demand forecasting, economics of renewable energy technologies, especially wind turbines.

Lars Henrik Nielsen, M.Sc. (Phys., Math.). Risø from 1981. Main activities: Probabilistic methods and model development, technical-economic modelling, and assessment of energy technologies, especially renewable energy, emissions calculations.

UNEP Collaborating Centre on Energy and Environment

John Møbjerg Christensen, M.Sc. (Eng.) Ph.D. Danish National Agency of Technology 1980-83, R&D initiation and administration, Oilconsult, Consulting Engineers and Planners 1983-84, R&D Energy Planning, NRSE projects. Risø from 1984. Energy Systems Group 1984-88. Programme Officer, Energy Unit, United Nations Environment Programme 1988-90. Head of UNEP Collaborating Centre on Energy and Environment from October 1990.

Gordon A. Mackenzie, B.Sc. Ph.D. (Physics). Guest researcher at Risø 1974-78. Lecturer at Edinburgh University 1978-79. Energy Systems Group from 1980. 1984 to 1987 Energy Adviser/ Deputy Director at Department of Energy, Zambia. From February 1988 until February 1990 leader of Environmental Modelling Group. From October 1990 with UNEP Collaborating Centre on Energy and Environment as senior energy planner. Main activities: integrated energy/environmental models, energy in developing countries.

Postgraduate Students

John Paulin Hansen, M.Sc. (Psychol). Major subject: Visual perception, recording of eye movements, evaluation of interfaces, cognitive modelling. Ph.D. student at Risø from 1988. Subject: Perception and cognition in complex work situations.

Lis Ketscher, M.Sc. (Psychol.). Danish Royal School of Education 1982-1985. Risø 1987-1988 as scientific assistant in a project on computer-assisted knowledge exploration, supported by the Danish Research Council for the Humanities. Main activities: Knowledge representation, knowledge structure, development of methods for probing mental models; problem solving and decision making. Ph.D. student at Risø from 1989. Subject: Knowledge acquisition and knowledge structures in computer-simulated task performance.

Søren Nors Nielsen, M.Sc. (Biol.), Major subject: Aquatic ecology and dynamical modelling of eutrophication processes. Ph.D. Student at Risø from 1989. Subject: Structural dynamical modelling of aquatic ecosystems and application of exergy as optimizing function.

Anette Schnipper, M.Sc. (Pharm.). The Royal Danish School of Pharmacy 1989-90. Ph.D. Student at Risø from 1990. Subject: Toxic Products in Smoke from Chemical Fires.

Lene Sørensen, M.Sc. (Eng.) Major subject: Strategies for Controlling Danish Waste Water Plants. Ph.D. student at Risø from April 1990. Subject: Integrated Environmental Models and Uncertainty.

Guest Researcher

Jan Scherfig, Ph.D.,Civil Eng. Professor of Environmental Engineering. University of California Irvine, 1969. University of California Scandinavian Study Center 1989-91. Main activities: Water reclamation and rinse, industrial waste treatment; eutrophication, biomass control; economic analysis of waste treatment systems.

Programmers

Maria Sonia Cirdenas Alvarado. Born in Chile. Educated programmer 1986 in Denmark. Risø from March 1987 until August 1990. Working on error identification and error analysis models.

Ulla Dollerup Hansen. Educated as programmer 1987. Risø from 1987 until December 1990. Computer programs for consequence modelling, and safety and reliability.

Søren Præstegaard, datanom. Regnecentralen 1973-79. Risø from 1979. Datanom with special subject: Optimization completed 1985 at EDP-school, Copenhagen. Working on simulation models, graphics, and general user support.

Einar Danielsen. Risø from 1985 until March 1990. Temporarily assigned to Systems Analysis Department. Working on development of environmental impact models.

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The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1990. The Department is made up of the Cognitive Systems Group, the Risk Analysis Group, the Energy Systems Group and the UNEP Collaborating Centre for Energy and Environment. The report includes a list of publications, lectures and staff members.

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